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SINTERIZACIÓN LÁSER EN PRÓTESIS REMOVIBLE, CONCEPTO, VENTAJAS Y DESVENTAJAS

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Resumen

Las prótesis parciales removibles (PPR) se fabrican tradicionalmente mediante una técnica de fundición a la cera perdida, sin embargo, se han desarrollado nuevos procesos de fabricación aditiva basados en sinterización láser para la fabricación rápida de estructuras metálicas de PPR a un bajo coste.

El uso de técnicas de diseño asistido por computadora y fabricación asistida por computadora (CAD-CAM), especialmente para la creación rápida de prototipos, impone un método más eficaz para fabricar las estructuras de PPR.

Las aleaciones Cr-Co tienen un amplio uso en la fabricación de las estructuras metálicas en las prótesis removibles por sus excelentes propiedades de biocompatibilidad, además de su alta resistencia a la corrosión y al desgaste, es por eso, que estas características lo han convertido en uno de los candidatos ideales para la confección de este tipo de prótesis.

Los rápidos avances en los procesos digitalizados continuarán, haciendo que esta técnica computarizada sea más rentable. Su desarrollo en la investigación permitirá que esta técnica se convierta más competitiva.

Abstract

Removable partial dentures (RPD) are traditionally manufactured using an investment casting technique, however, new additive manufacturing processes based on laser sintering have been developed for the rapid manufacture of RPD metal structures at a low cost.

The use of computer aided design and computer aided manufacturing (CAD-CAM) techniques, especially for rapid prototyping, imposes a more efficient method for fabricating RPD structures.

Cr-Co alloys are widely used in the manufacture of metal structures in removable prostheses due to their excellent biocompatibility properties, in addition to their high resistance to corrosion and wear, that is why these characteristics have made it one of the ideal candidates for the manufacture of this type of prosthesis.

Rapid advancements in digitized processes will continue, making this computerized technique more profitable. Its development in research will allow this technique to become more competitive.

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1. INTRODUCCIÓN

La sinterización láser es un proceso de fabricación 3D descrito por primera vez por Deckard y Beaman alrededor de 1989.[2][9] Este proceso se basa en la impresión tridimensional de un objeto, mediante la fusión de polvos gracias a la tecnología láser y la interposición de capas extremadamente finas. [2].

Todo este desarrollo ha sido posible gracias a que durante los últimos años la impresión 3D ha ido avanzando a grandes pasos, convirtiendo cada vez más la odontología moderna en una odontología digital.

La impresión 3D es un proceso mediante el cual se colocan capas sucesivas de un material hasta crear el objeto tridimensional. Este es muy diferente a otros tipos de fabricación como puede ser la sustractiva, mediante el fresado CAM (fabricación asistida por ordenador), donde se va fresando un bloque, de un determinado material, hasta crear el objeto final.

Todo este proceso es totalmente digital, comenzando por la fabricación digital del objeto 3D mediante un diseño asistido por ordenador (CAD) y su posterior fabricación asistida por ordenador (CAM). Estos datos digitales del objeto 3D van a ser seccionados en delgadas capas 2D utilizando específicos programas de software para posteriormente poder ser enviados a la impresora capa por capa, gracias al CAM, para que estas se vayan formando con la mayor precisión posible y así confeccionar nuestro objeto 3D.

Esos datos de archivos CAD pueden ser creados de dos formas. Por un lado, escaneando ópticamente un objeto 3D o, por otro lado, diseñando el objeto 3D en un software específico.

Los distintos softwares crean un archivo STL (STereoLithography) que luego se usa para confeccionar la estructura metálica. La mayoría de las impresoras 3D son capaces de producir un archivo de trabajo a partir de un archivo STL. [2]

La obtención de todos los datos 3D lo conseguimos mediante el escaneado previo de nuestro modelo de trabajo y su posterior confección de la estructura metálica sobre él.

Durante los últimos años, se han utilizado técnicas de impresión convencionales para registrar la geometría tridimensional de los tejidos dentales. Sin embargo, los cambios volumétricos de los materiales de impresión y la expansión de la escayola parecen ser propensos a errores y, por lo tanto, el proceso requiere los servicios de un excelente laboratorio dental. Para superar estas dificultades, se desarrolló la impresión con escáneres intraorales para la práctica dental.

El escáner intraoral es un dispositivo que reproduce en imágenes tridimensionales las estructuras de la cavidad bucal, permitiendo así crear un conjunto de documentos digitales para poder trabajar sobre él.

Para crear esto, una fuente de luz y la unidad receptora están en un ángulo específico entre sí; esta angulación permite que la computadora produzca un conjunto de datos tridimensionales a partir de la imagen en la unidad receptora.

En general, existen dos tipos de escáneres intraorales en el mercado. El primero utiliza un LED azul (diodo emisor de luz) dónde estos sistemas dependen de una superficie reflectante y requieren que se coloque polvo de contraste sobre las estructuras que se escanean. Los otros sistemas utilizan tecnología láser para escanear y medir distancias desde la superficie del diente para adquirir la imagen, estos, no requieren polvo. [2]

Esta expansión de la impresión 3D ha llegado a grandes campos de la medicina gracias a la capacidad que tiene de poder personalizar equipamiento médico a un precio razonablemente barato. Y es por ello, que desde aproximadamente el año 2000 se ha ido implementando cada vez más en el ámbito odontológico. [2] [7]

Tabla 1. Beneficios y desafíos en la utilización de la impresión 3D en odontología.

BENEFICIOS	DESAFÍOS
Ahorro de materiales (en comparación con el proceso de fresado sustractivo tradicional de metal o cerámica, o la técnica convencional de fundición a la cera perdida)	Al comenzar, el equipamiento necesario es caro
Varios trabajos pueden ser fabricados al mismo tiempo	Necesita una formación adecuada en el uso de maquinaria y los programas de software
Capacidad ilimitada de diseño y fabricación (a diferencia de las fresadoras que están limitadas por su eje de fresado) permitiendo personalización, flexibilidad y libertad geométrica.	Si se utilizan técnicas convencionales en la toma de impresiones y el moldeado de impresiones, esto podría ser una fuente de error
Podemos volver a hacer exactamente o se puede modificar el diseño cuando sea necesario si guardamos los datos CAD	Los fallos conllevan-defectos: superficie rugosa, poros, grietas y distorsión, pero a menudo se pueden corregir con procedimientos de acabado y pulido. Y se pueden reducir utilizando un grosor de capa pequeño y un diámetro de laser pequeño.
Alta reproductibilidad del diseño (CAD) en la prótesis real, con inclusiones reducidas, defectos o distorsiones (que ocurren muy comúnmente en procesos de fundición manual)	

Capacidad de producir superficies complejas muy detalladas	
Procesos de post-procesado más simples	
Desperdicio mínimo (gran diferencia frente a las fresadoras)	

Fuente: Dominic P Laverty, Matthew BM Thomas, Paul Clark and Liam D Addy [2]

Cada día la odontología contemporánea se acerca más a convertirse en una odontología digital y debemos conocer las alternativas que la sinterización láser nos puede llegar a ofrecer.

1.1 DEFINICIÓN

La sinterización laser (DMLS) es un proceso de fabricación digital que va asociado a lo que hoy en día se conoce como el CAD/CAM (diseño asistido por ordenador y fabricación asistida por ordenador). [13] Este sistema nos permite diseñar desde diferentes tipos de prótesis dentales (fijas, parciales y removibles), como la impresión de provisionales y cofias metálicas para nuestras futuras rehabilitaciones.

El CAD, lo que conocemos como diseño asistido por ordenador, se basa en la creación de un objeto 3D de dos formas diferentes. La primera, escaneando ópticamente un objeto 3D mediante un proceso llamado ingeniería inversa o diseñando el objeto 3D utilizando un software CAD.

Estos archivos digitales CAD del objeto 3D se divide en secciones delgadas 2D utilizando programas de software. Estos datos seccionados se envían a la impresora capa por capa utilizando CAM para que cada capa se forme con precisión y se construya sucesivamente para producir el objeto 3D.

Por ello la sinterización láser tiene una estrecha relación con este proceso ya que consiste en la formación de una fina capa de entre 20 y 100 micras mediante el sinterizado láser para así formar una sección transversal en 2D. Posteriormente se produce una interposición capa por capa distribuyendo una capa uniforme de polvo metálico para producir el objeto tridimensional (3D). [2]

Los laboratorios dentales avanzan y se adaptan al mismo ritmo que evoluciona la odontología, donde el CAD/CAM, es una herramienta básica actualmente en la mayoría de ellos.

El uso del CAD/CAM esta cada día más generalizado en cuánto a la fabricación de las estructuras metálicas en prótesis removibles. Todo el proceso que nos lleva a determinar la inserción y desinserción de la prótesis, el diseño de la estructura y crear el modelo de trabajo con su respectivo encerado, hoy en día, podemos diseñarlo todo digitalmente.

Es por ello que al no tener que hacer duplicados y modelos refractarios como haríamos en el método convencional. Esta digitalización nos va a simplificar la fabricación ahorrándonos tiempo y coste en la confección de estas prótesis.

1.2 MÉTODOS DE FABRICACIÓN

La prótesis removible es una de las opciones terapéuticas más utilizadas para reponer la falta de dientes en pacientes con edentulismo parcial. Esto se debe básicamente a que es una de las opciones más conservadoras y asequibles, que mejorará la calidad de vida de los pacientes.

Hay que tener en cuenta la importancia de la prótesis removible ya que cuando hay una pérdida de piezas dentales, y estas, no son repuestas. Se pueden producir desequilibrios entre los dientes adyacentes e incluso la reabsorción ósea de esas zonas edéntulas. [18]

Durante los últimos años se han utilizado diversos materiales para la fabricación de este tipo de prótesis, y entre ellos, las prótesis metálicas fabricadas mediante sinterización láser. [7] [18]

La fabricación de este tipo de prótesis mediante sinterización laser nos ofrece una gran precisión en el diseño de estas, y es por ello, que su uso actualmente está incrementando debido a que conseguimos mejores resultados de ajuste y estabilidad en la boca del paciente.

Una de las propiedades más esenciales en la duración y mantenimiento de una prótesis dental metálica, es su correcto ajuste marginal. Cuanta más precisión se consiga en la fabricación de la prótesis menos efectos nocivos, como caries (especialmente caries radiculares), periodontitis, candidiasis oral, estomatitis y halitosis, que pueden surgir de la placa que se acumula alrededor de una prótesis parcial, tendrá el paciente. [1] [18]

En la actualidad existen dos métodos para la fabricación de estas prótesis removibles.

1.2.1 MÉTODO TRADICIONAL (FUNDICIÓN A LA CERA PERDIDA)

Por un lado, tenemos el método tradicional utilizado desde hace más de un siglo, la técnica de fundición a la cera perdida. La técnica de fundición es un proceso manual bastante laborioso que consiste en realizar una réplica en cera de nuestra prótesis dental, hacer una impresión de la prótesis, y luego verter todo el material fundido en nuestra impresión. Debido a la complejidad que comprende esta técnica, está altamente influenciada por la habilidad del técnico dental.

Además, la producción de una prótesis removible mediante la técnica de fundición no solo requiere mucho tiempo y coste, si no que a su vez puede generar estructuras de baja precisión y con mal ajuste. [7]

En cambio, por otro lado, tenemos la opción 3D, el sinterizado láser mediante el uso de polvos de distintos materiales.

Esta tecnología de sinterización laser puede describirse con diferentes terminologías como, fusión selectiva por láser (SLM), sinterización directa por láser de metales (DMLS) y sinterización selectiva por láser. [2]

Cuando hablamos del SLM nos referimos a la fusión del polvo metálico, mientras que el SLS y DMLS es la fusión parcial del polvo metálico. La principal diferencia que hay entre el SLS y el DMLS es que, el polvo de este primero puede ser metal u otros materiales como cerámica o polímeros. En cambio, el DMLS es una mezcla de polvos metálicos con diferentes temperaturas de fusión (altas o bajas). [7] [13]

1.2.2 SINTERIZADO DIRECTO DE METAL POR LÁSER (DMLS)

En el caso de prótesis removible, el DMLS es el proceso más utilizado para su confección. La estructura 3D que hemos confeccionado previamente, debe estar apoyada adecuadamente durante todo el proceso de impresión. Para ello debe tener estructuras de soporte diseñadas en el software sobre el objeto 3D. La estructura de soporte asegura que el objeto esté fijo en relación a la posición de la placa base de la impresora y asegura la posición geométrica, que es una parte vital en el proceso DMLS. Estas estructuras de soporte deberán ser posteriormente retiradas una finalizado el proceso de confección de la prótesis. [Figura 2] [16]

El proceso **DMLS** es realizado por dos métodos: deposición de polvo y lecho de polvo; ambos difieren en la forma en que se aplica cada capa de polvo. [2]

-En el método de **deposición de polvo**, el polvo metálico se sinteriza en un recipiente y luego se deposita en una capa delgada sobre la plataforma de construcción.

-En el método de **lecho de polvo**, un brazo distribuye una capa fina de polvo sobre el lecho de polvo y luego se sinteriza.

En ambos métodos, las capas son construidas una encima de otra con la plataforma de construcción descendiendo cada vez más para permitir la aplicación de la siguiente capa de polvo.

El método de lecho de polvo es actualmente el más utilizado, ya que ofrece velocidades de confección más rápidas. Dentro del área de la cámara de construcción, hay dos plataformas, la plataforma de distribución de material y la plataforma de construcción [Fig. 1]. La plataforma dispensadora de material junto con una cuchilla de recubrimiento mueve el polvo nuevo sobre la plataforma de construcción. El polvo de metal se convierte en una estructura sólida fundiéndola gracias a la proyección del rayo láser. Las piezas se acumulan capa a capa, con un espesor de 20 micras normalmente. Después de construir una capa, el pistón de construcción baja la plataforma de construcción y se aplica la siguiente capa de polvo. Este proceso permite crear geometrías altamente complejas directamente a partir de los datos CAM en 3D, de forma totalmente automática sin herramientas, produciendo piezas con mayor precisión y resolución detallada, buena calidad superficial y excelentes propiedades mecánicas. Una vez completado, se elimina el exceso de polvo y se separa cuidadosamente la estructura metálica de la placa base. Después debemos someter la estructura metálica en un proceso de tratamiento térmico llamado recocido que hace avanzar el material a su estado de equilibrio. [13]

Esto implica calentar la estructura por encima de la temperatura crítica y luego enfriarla. Este proceso de recocido produce una estructura metálica más homogénea, y afecta a la microestructura y dureza de la aleación.

Por último, para terminar con la confección, eliminaremos las estructuras de soporte, haremos un arenado, pulido y limpieza con ultrasonidos. [2][13]

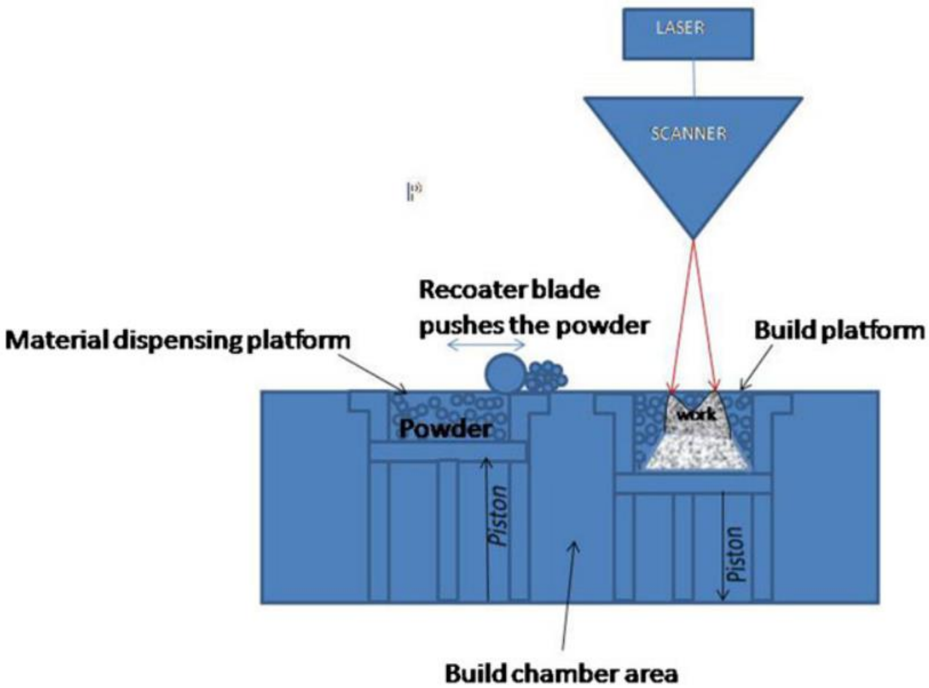

Figura 1. Representación esquemática de proceso DMLS. [13]

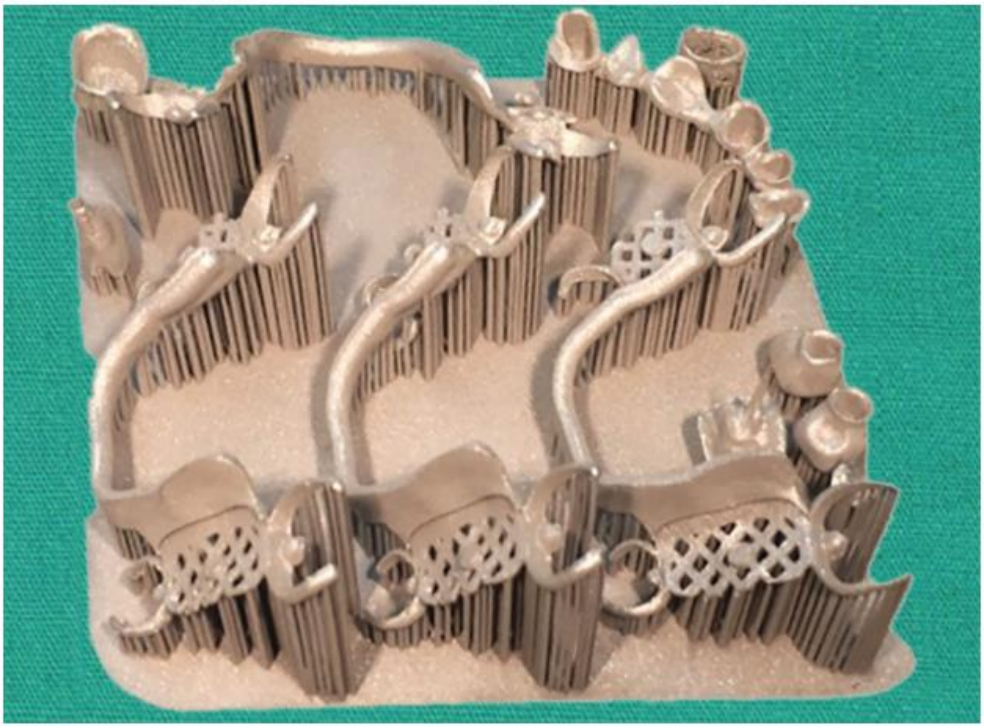

Figura 2. Estructura metálica definitiva producida con Cr-Co. [16]

Las prótesis parciales removibles contienen varios componentes principales y entre ellos se encuentran los retenedores. Gracias a la técnica CAD/CAM estos retenedores se pueden fabricar con una mayor precisión que con la técnica convencional a la cera perdida. Esto conlleva a que nuestra futura prótesis tenga un ajuste significativamente mejor al de las convencionales.

Estos componentes son fabricados mediante aleaciones normalmente de Cromo-Cobalto, dando como resultado estructuras más precisas y presentando mejor resistencia a la fatiga y propiedades mecánicas para las PPR que las aleaciones fundidas debido a su mejor homogeneidad y tamaño de grano pequeño. [7]

En la fabricación de las prótesis debemos tener en cuenta varios factores que pueden determinar su confección, y entre ellos, se encuentra la forma del paladar. Se ha observado que las prótesis realizadas por CAD / CAM y por el método de inyección tienen una adaptación significativamente mejor que las prótesis confeccionadas por el método de compresión para paladares poco profundos. El método de inyección puede ser indicado para pacientes con arcos maxilares ovoides poco profundos específicamente. [3]

En cuanto, La fabricación de prótesis removibles mediante la técnica de sinterización láser, en lugar de la técnica de fundición, puede aumentar la calidad de las prótesis removibles y hacer que el tratamiento sea menos costoso y más accesible para una mayor parte de la población. Sin embargo, la fabricación de prótesis removible de Cr-Co mediante tecnología de sinterización láser puede afectar los aspectos mecánicos, físicos, y las propiedades de biocompatibilidad de las aleaciones y posteriormente afectando el desempeño clínico de las prótesis removibles. [Figura 3]

Las propiedades de las aleaciones sinterizadas por láser pueden verse influenciadas por diferencias en el proceso de fabricación cómo:

- La potencia del láser
- La velocidad de escaneo
- El tamaño del polvo de los metales
- El espesor de capa

La propiedad mecánica, como el módulo elástico y el límite elástico a la flexión, es crucial para las prótesis removibles porque evita que los ganchos, los elementos retentivos de la prótesis removible, sufran un fallo durante los ciclos repetitivos de inserción y extracción de la prótesis en la boca. Sin embargo, actualmente no hay datos disponibles sobre la resistencia a la fatiga de las aleaciones de las prótesis removibles sinterizadas con láser. [7] [18]

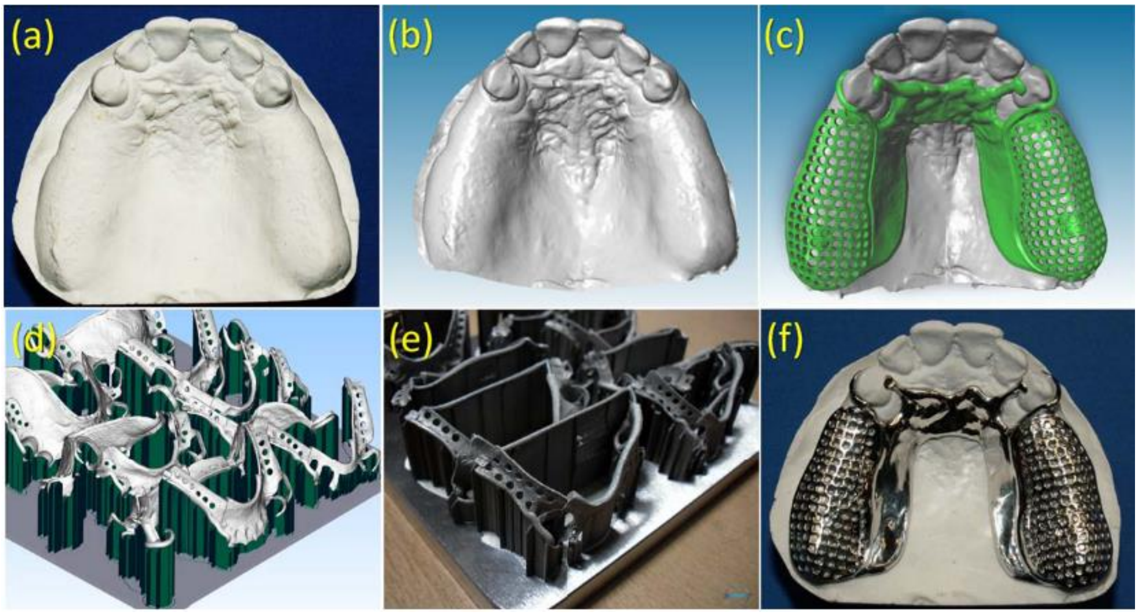

Figura 3. Fotografías que ilustran el proceso de diseño y fabricación de estructuras de prótesis parciales removibles (PPR) utilizando la técnica de sinterización por láser: (a) modelo maestro de arcada parcialmente desdentada, (b) escaneado 3-D del modelo, (c) diseño de estructuras PPR, (d) colocar marcos de PPR en una plataforma digital, (e) marcos de PPR procesados en la plataforma de producción, y (f) el marco de PPR final. [7]

1.3 MATERIALES Y PROPIEDADES

Para la confección de una prótesis removible necesitamos obtener una estructura con materiales que tengan unas propiedades específicas. Es por ello, que en general, los dos metales primarios más utilizados son el Titanio (Ti) y Cromo-Cobalto (Co-Cr) ya que ambos son los más viables para la impresión 3D en odontología.

En el caso del polvo de Co-Cr, su composición será básicamente Cromo y Cobalto, pero a su vez están presentes compuestos como el molibdeno, tungsteno, silicio, cerio, hierro, manganeso y carbono. Dado que el Co es el elemento metálico predominante, es importante mencionar que la aleación debe denominarse aleación Co-Cr en lugar de aleación Co-Cr ya que las aleaciones deben comenzar con el nombre del elemento predominante. En el caso del Co, su estructura inestable está asociada con algunas propiedades características de las aleaciones de Co, como puede ser el alto límite elástico, altas tasas de endurecimiento por trabajo, daño limitado por fatiga debido a tensiones cíclicas y la capacidad de absorber tensiones. [13][24]

Por otro lado, el Cr es el otro elemento de aleación principal y se agrega para aumentar la resistencia, debido a la formación de carburo, y para mejorar la resistencia a la corrosión y la oxidación.

Sin embargo, las aleaciones dentales de Co-Cr utilizadas para DMLS tienen poca evidencia científica que nos informen sobre sus verdaderas características.

La evidencia actualmente disponible nos aporta que la técnica de fabricación, ya sea colada convencional, sinterización por láser o fresado con aleaciones dentales de Co-Cr, tiene propiedades mecánicas adecuadas que satisfacen las normas ISO de aleaciones dentales.

En cuanto a las aleaciones de Titanio, cabe destacar que están siendo cada vez más investigadas y se ha concluido que sus ventajas en comparación con las técnicas convencionales se basan en una excelente resistencia a la corrosión, propiedades mecánicas óptimas, un peso ligero, una mayor precisión en el ajuste y menos posibilidad de reacción alérgica debido a su gran biocompatibilidad. [11]

En relación a los posibles problemas que pueden tener las aleaciones de Titanio se encuentran posibles defectos en la fundición del Titanio, el despegamiento de la resina sobre la base de la prótesis, la oxidación del metal, una deficiencia en la manipulación y corte de la estructura de Titanio, un deficiente pulido, descoloramiento del metal, la adherencia de la placa dental a la prótesis y el posible desgaste severo de los dientes de Titanio. Por último, cabe mencionar que algunos pacientes han podido reconocer un pequeño gusto extraño en la prótesis, aunque su etiología es aún desconocida. [9][11][13][24][25]

Hay casos en los que en los pacientes parcialmente desdentados que prefieren no tener metal en su estructura de la prótesis y / o ganchos. Los componentes principales se pueden fabricar utilizando resina de base de poliamida de nailon flexible. Desafortunadamente, estos diseños de PPR no tienen componentes de desplazamiento vertical (apoyos metálicos) y deben apoyarse en el tejido blando como soporte. [18]

Al final la impresión 3D nos está ofreciendo un método de trabajo mucha más rápido y rentable y desde principios de la década de 2000, las dentaduras parciales siguen siendo un tratamiento muy reconocido. Sin embargo, aunque los avances de la digitalización odontológica son muy grandes y rápidos, la literatura no ha publicado grandes comparaciones entre la fabricación convencional y CAD/CAM. Es un concepto actual que evoluciona cada vez más y probablemente en un futuro se convierta en nuestro día a día.

2. OBJETIVOS DEL TRABAJO

Este trabajo tiene como **objetivo principal**:

- Describir el concepto y sistemática de la sinterización láser en prótesis removible.

Desarrollando a su vez unos **objetivos secundarios** que serán:

1. Describir las características y propiedades
2. Comparar con el método tradicional
3. Describir las ventajas y desventajas

3. MATERIALES Y MÉTODOS

Este trabajo es una revisión bibliográfica, por lo que se ha basado en la búsqueda de artículos publicados en PubMed, Google Académico y Medline. Los criterios de inclusión para el estudio fueron: buscar artículos en inglés debido a que es un tema actual dónde la mayoría de ellos se encuentran en revistas de alto impacto y, además, que estuviesen en un rango de 10 años de antigüedad.

En la búsqueda de estos artículos se han utilizado palabras clave como pueden ser: sinterización láser, prótesis removible, impresión 3D, CAD/CAM, Cr-Co. Se han utilizado un total de 26 artículos con un rango de búsqueda de 7 años (2013-2020).

Los criterios de exclusión de artículos que se han seguido en la revisión son los siguientes:

Se han descartado algunos artículos debido a que, aunque se centrasen en la sinterización láser, se basaba todo su uso en la fabricación de implantes y prótesis fija, que no es el objetivo de este trabajo.

La mayoría de los artículos que han sido seleccionados es debido a que el tema principal es la sinterización láser y nos han podido aportar datos que aclaren el concepto de la sinterización laser y comparen sus diferentes características en relación a su implementación en las prótesis removibles.

Muchos otros han sido seleccionados debido a que, aunque el tema principal no fuese la sinterización láser en prótesis removible, nos aportaba información sobre la impresión

3D, método de fabricación, materiales para la confección y sus diferentes usos en el campo de las prótesis removibles.

4. DISCUSIÓN

Las prótesis parciales removibles son muy recomendadas para una gran variedad de defectos dentales, con ventajas, tales como una preparación mínima del diente, facilidad en la limpieza y reparación y su bajo costo. Las prótesis parciales removibles pueden mejorar la calidad de vida de los pacientes de una manera sencilla y eficaz y tienen una vida útil prolongada.

El flujo de trabajo digital se ha vuelto popular para hacer las estructuras de las PPR, escaneando y planificando las prótesis. Las estructuras metálicas realizadas para este tipo de prótesis deben satisfacer las necesidades biomecánicas y funcionales óptimas para nuestro paciente. El ajuste de la estructura de la prótesis parcial removible es uno de los requisitos más importantes para el éxito de esta. Un ajuste inadecuado puede promover el movimiento de los dientes y la incomodidad del paciente, siendo la mala adaptación la razón principal por la que no se utilizan muchas prótesis removibles. [16] [17] [23]

Según la teoría, la impresión directa con tecnología CAD, más específicamente la tecnología de fusión selectiva por láser (SLM), tiene el potencial de ser más precisa que la fabricación de estructuras convencionales porque se necesitan menos pasos, lo que potencialmente reduce el número de errores en la fabricación. Se han demostrado resultados clínicamente aceptables para las estructuras de las PPR fabricadas con tecnología SLM dónde han informado que tienen propiedades mecánicas mejoradas, mayor satisfacción del paciente, menor tiempo de laboratorio y disponibilidad de datos digitales guardados para la futura reproducción de prótesis si fuese necesario. [7] [8] [14] [16] [20]

La fabricación convencional de prótesis parciales removibles (RPD) es un proceso complejo, propenso a errores, lento y costoso. Los sistemas PPR de diseño asistido por computadora y fabricación asistida por computadora (CAD-CAM) pueden simplificar los pasos clínicos y minimizar los errores.

4.1 PRECISIÓN EN EL AJUSTE SEGÚN EL MÉTODO DE FABRICACIÓN

La mayoría de los autores afirman que existe una diferencia considerable entre la fabricación de las prótesis de manera convencional y mediante un flujo digital. La fabricación selectiva por láser CAD-CAM se ha comparado con el método convencional teniendo en cuenta los valores de discrepancias más representativos en las PPR indirectas (patrón impreso en 3D seguido de la técnica de fundición a la cera perdida) y directos (mediante una fusión selectiva por láser). Defienden qué en los procesos directos e indirectos, el posicionamiento de la estructura de soporte es de gran importancia, sobre todo cuando la prótesis maxilar es fina y ocupa un área mayor. Además, las propiedades del material y las condiciones de temperatura utilizadas durante la sinterización son también factores a tener en cuenta.

A pesar de los mayores desajustes, diferentes estudios han presentado una diferencia clínicamente aceptable entre la estructura y los dientes pilares preparados. Por lo tanto, para los RPD, la precisión considerada clínicamente aceptable se encuentra dentro de un rango de tolerancia más amplio en comparación con la de las prótesis fijas. Esto ocurre debido a que el reborde residual es elástico y se desplaza bajo presión. [15] [23]

Otros autores como Tregerman, Renne, Kelly y Wilson investigan el nivel de precisión y ajuste en la confección de las prótesis mediante la diferenciación de los métodos de fabricación. Crean estructuras de PPR mediante el uso de 3 métodos de fabricación diferentes: analógico (técnica convencional), analógico-digital combinado (escayola + escáner extraoral + impresión 3D) y digital (escaneo intraoral + impresión 3D). Posteriormente se ha visto que el método completamente digital era significativamente mejor que el método tradicional de fabricación y que el escaneo intraoral también mostro mejores resultados que el método combinado de fabricación. [1] [21] [23]

Por otro lado, la forma del paladar es un gran factor a tener en cuenta con respecto al ajuste de las PPR. Según los estudios previos llevados a cabo por Bryan McLaughlin, Van Ramos y Dickinson. Normalmente, hay entre un 41% y un 47% más de espacio debajo de la prótesis realizada bajo el método de compresión que una prótesis por inyección o CAD / CAM. La mayor parte de esta diferencia de espacio se encuentra en los grupos de paladares poco profundos, que son más susceptibles a contraerse. Los odontólogos que busquen obtener el mejor ajuste de las prótesis pueden considerar el uso de CAD / CAM o método de inyección para pacientes con paladares poco profundos, ya que estos tienen el potencial de producir menos molestias para el paciente y menos ajustes posteriores. [3]

Finalmente, gran cantidad de autores como Tasakaa, Shimizua, Katoa, Okanoa, Idaa, Higuchib, Yamashita coinciden en sus conclusiones con que la sinterización láser es un proceso de fabricación que ofrece una mayor velocidad y flexibilidad al eliminar muchos pasos físicos necesarios en la fundición a la cera perdida. Por lo tanto, la decisión de elegir una técnica en particular sobre otra puede depender de las condiciones económicas del paciente. Aunque ambas técnicas requieren un acabado manual, las estructuras producidas por SLM ofrecen mejores resultados clínicos ya que este proceso se controla digitalmente y, por lo tanto, ofrece un método estándar para la fabricación de dispositivos dentales. [23]

Sin embargo, cabe destacar, que autores como O Bajunaid, Altwaim, Alhassan y Alammari indican que no hay una diferencia significativa entre el proceso digital y convencional. Afirman que ambos se encuentran en un rango aceptable para el uso clínico, incluso, han llegado a revelar que las estructuras de RPD procesadas mediante un método convencional tienen un mejor ajuste y precisión en comparación con las estructuras impresas en 3D. [1] [16] [23]

4.2 ALEACIONES DE CROMO-COBALTO

Autores cómo Peng, Hsu, Huang, Chao y Lee afirman que las aleaciones de Co - Cr procesadas mediante técnicas de sinterización por láser son más precisas y presentan mejor resistencia a la fatiga y propiedades mecánicas para las PPR que las aleaciones fundidas debido a su mejor homogeneidad y tamaño de grano pequeño. Además, tanto las aleaciones de Co - Cr sinterizadas por láser como las fundidas presentan propiedades de biocompatibilidad similares. Además, las PPR sinterizadas con láser pueden presentar beneficios clínicos sobre los fundidos en términos de ajuste y estabilidad mecánica. [22]

Muchos otros autores como Schweiger, Güth, Erdelt, Edelhoff, Schubert afirman que las aleaciones de Co-Cr producidas por SLM poseen propiedades mecánicas adecuadas para su uso clínico y son superiores a las aleaciones de Co-Cr fundidas.

Estas propiedades mecánicas están estrechamente relacionadas con su microestructura. Yager encontró que la aleación de Co-Cr producida por SLM posee una homogeneidad superior con un tamaño de grano más pequeño (5–80 µm) en comparación con la aleación de Co-Cr fundida (200–300 µm). Los tamaños de grano pequeños en el proceso SLM aumentan el límite elástico de la aleación y se forman como resultado de una rápida solidificación y poca segregación de los elementos de aleación. En general, las propiedades mecánicas superiores de las aleaciones dentales se traducen en una mayor resistencia a la distorsión y una transmisión eficiente de fuerzas a los dientes restantes u otros tejidos. [19]

Estas también son importantes para lograr un acabado que respete la anatomía del tejido, que se logra mediante el pulido electrolítico, para así evitar problemas de ajuste y limpieza en la superficie de ajuste de las estructuras de Co-Cr.

A su vez autores como Schweiger, Güth, Erdelt, Edelhoff y Schubert han comprobado que las condiciones metalúrgicas en las que estas aleaciones se procesan difieren sustancialmente de los de la fundición convencional, por lo que es posible que las diferentes microestructuras puedan alterar posteriormente las propiedades físico-mecánicas de los componentes individuales que forman los marcos producidos por SLM. El tratamiento térmico a 1150 ° C durante 6 horas induce a la fase frágil a cambiar a una fase dúctil. [11] [12] [24]

En cuanto a la fabricación de las retenciones en las prótesis removibles se han comprobado que los ganchos sinterizados con láser presentan unas características superiores a los convencionales. Los ganchos sinterizados por láser (DMLS) han mostrado un volumen más pequeño y una distribución más homogénea de las porosidades internas en comparación con las muestras fundidas. En cuanto a los valores de fuerza de retención de los cierres DMLS mostraron una consistencia superior a lo largo del tiempo. Y en relación a la supervivencia a largo plazo de los ganchos de DMLS ha sido considerablemente más alta que la de los ganchos convencionales. [5] [12] [19]

Se ha comprobado a su vez que la superficie del gancho CAM era más lisa que la de los cierres de Co-Cr y Ti fundidos. Las distancias de los espacios en las regiones de descanso del cierre CAM son significativamente mayores que las de los retenedores fundidos. Se observaron distancias de separación similares entre el brazo reciprocador y la punta de todos los ganchos. Y a su vez las fuerzas de retención de los retenedores colados y CAM Co-Cr se ha comprobado que son significativamente más altas que las del brazo de Ti. [4] [10] [22]

Finalmente, en relación al sistema DMLS, se ha comprobado que la rugosidad de la superficie de las aleaciones producidas a través de DMLS está influenciada por la orientación de la superficie sinterizada a la dirección de construcción. Esta varía dependiendo de la relación de la muestra con la dirección de construcción, y se ha visto que cuanto menor es la inclinación, menor es la rugosidad de la superficie. [6]

4.3 SATISFACCIÓN DE LOS PACIENTES

La comodidad en el día a día en los pacientes es un factor básico y quizás de los más importantes para ellos. Por ello, se realizó un estudio en el que compararon la satisfacción a corto plazo en pacientes que usaban PPR fabricadas con tecnología de sinterización láser convencional o CAD-CAM. Se escogieron a doce participantes con edentulismo parcial y fueron asignados aleatoriamente a usar prótesis removible sinterizadas con láser mediante CAD-CAM durante períodos alternos de 30 días.

Una vez terminado el proceso los pacientes concluyeron diferentes opiniones. Los participantes estaban más satisfechos con la capacidad del habla cuando utilizaban la PPR sinterizada con láser que la PPR fundida (probablemente debido a la mejor estabilidad y retención). También mostraron un mayor grado de satisfacción con la capacidad masticatoria y la eficacia de las prótesis sinterizadas con láser que con las prótesis convencionales (esto podría explicarse por la estabilidad de las prótesis). En cuanto a la estética, no existen diferencias significativas en la satisfacción de los participantes, pero, en términos de capacidad de limpieza, los participantes estaban significativamente más satisfechos con las PPR sinterizados con láser.

Finalmente, el índice de satisfacción de las PPR sinterizadas con láser aumentó gradualmente con el tiempo. Esto puede indicar que los participantes tuvieron un período de adaptación más fácil utilizando PPR sinterizadas con láser en lugar de fundidas. El uso de tecnología de sinterización láser para la fabricación de PPR puede conducir a una mayor satisfacción a corto plazo para los pacientes con edentulismo parcial que los métodos convencionales. [8]

5. CONCLUSIONES

En primer lugar, podemos concluir con que la sinterización láser es una técnica de impresión 3D relativamente nueva, su uso en las prótesis removibles produce una mejora en el ajuste y precisión, unos procedimientos de postprocesado simplificados, libre de porosidad a diferencia de las estructuras confeccionadas de manera convencional y características biomecánicas mejoradas.

En segundo lugar, la sinterización láser nos ofrece ventajas donde la adaptación de las estructuras impresas con SLM son significativamente mejor a las de las estructuras fundidas, excepto para algunas estructuras grandes o complejas.

Es un método de confección donde se deben estudiar aún muchos factores y es por ello, que aún no existe una información que nos confirme con exactitud el potencial de este método en la fabricación de las prótesis removibles.

Es una técnica relativamente nueva para producir estructuras de PPR metálicas y se está introduciendo poco a poco en la práctica clínica; sin embargo, la investigación sobre su utilidad clínica en comparación con los métodos tradicionales es limitada y el proceso implica equipos y procesos costosos a los que los odontólogos pueden no estar acostumbrados. Se recomienda que se lleven a cabo ensayos clínicos a largo plazo para proporcionar evidencia que respalde aún más esta técnica.

6. GLOSARIO

- CAD: Diseño asistido por ordenador
- CAM: Fabricación asistida por ordenador
- DMLS: Sinterizado directo de metal por láser
- SLM: Sinterizado selectivo por láser
- PPR: Prótesis parcial removible
- STL: STereoLithography

7. RESPONSABILIDAD

El uso de la sinterización láser en la confección de prótesis removibles supone una mejora en el campo periodontal, restaurador de la odontología actual. Además, supone ciertos beneficios:

- Favorece al paciente ya que puede mejorar su calidad de vida con una mejor estabilidad y retención de la prótesis.

- Económicamente beneficioso debido a que podemos evitar defectos que conlleven a la confección de una nueva prótesis.

- El avance en el conocimiento de nuevas tecnologías permite contribuir que a nivel ambiental es un procedimiento completamente sustentable.

8. BIBLIOGRAFÍA

1. Carneiro Pereira AL, Bezerra de Medeiros AK, de Sousa Santos K, Oliveira de Almeida É, Seabra Barbosa GA, da Fonte Porto Carreiro A. Accuracy of CAD-CAM systems for removable partial denture framework fabrication: A systematic review. J Prosthet Dent [Internet]. 2020;1–8. Available from: https://doi.org/10.1016/j.prosdent.2020.01.003

2. Laverty DP, Thomas MBM, Clark P, Addy LD. The use of 3D metal printing (direct metal laser sintering) in removable prosthodontics. Dent Update. 2016;43(9):826–35.

3. McLaughlin JB, Ramos V, Dickinson DP. Comparison of Fit of Dentures Fabricated by Traditional Techniques Versus CAD/CAM Technology. J Prosthodont. 2019;28(4):428–35.

4. Nakata T, Shimpo H, Ohkubo C. Clasp fabrication using one-process molding by repeated laser sintering and high-speed milling. J Prosthodont Res [Internet]. 2017;61(3):276–82. Available from: http://dx.doi.org/10.1016/j.jpor.2016.10.002

5. Alsheghri AA, Alageel O, Caron E, Ciobanu O, Tamimi F, Song J. An analytical model to design circumferential clasps for laser-sintered removable partial dentures. Dent Mater [Internet]. 2018;34(10):1474–82. Available from: https://doi.org/10.1016/j.dental.2018.06.011

6. Aarts JM, Choi JJE, Metcalfe S, Bennani V. Influence of build angulation on the mechanical properties of a direct-metal laser-sintered cobalt-chromium used for

removable partial denture frameworks. J Prosthet Dent [Internet]. 2020;1–7. Available from: https://doi.org/10.1016/j.prosdent.2020.06.014

7. Alageel O, Abdallah MN, Alsheghri A, Song J, Caron E, Tamimi F. Removable partial denture alloys processed by laser-sintering technique. J Biomed Mater Res - Part B Appl Biomater. 2018;106(3):1174–85.

8. Almufleh B, Emami E, Alageel O, de Melo F, Seng F, Caron E, et al. Patient satisfaction with laser-sintered removable partial dentures: A crossover pilot clinical trial. J Prosthet Dent. 2018;119(4):560-567.e1.

9. Revilla-León M, Meyer MJ, Özcan M. Metal additive manufacturing technologies: literature review of current status and prosthodontic applications. Int J Comput Dent [Internet]. 2019;22(1):55–67. Available from: http://www.ncbi.nlm.nih.gov/pubmed/30848255

10. Torii M, Nakata T, Takahashi K, Kawamura N, Shimpo H, Ohkubo C. Fitness and retentive force of cobalt-chromium alloy clasps fabricated with repeated laser sintering and milling. J Prosthodont Res [Internet]. 2018;62(3):342–6. Available from: https://doi.org/10.1016/j.jpor.2018.01.001

11. Barucca G, Santecchia E, Majni G, Girardin E, Bassoli E, Denti L, et al. Structural characterization of biomedical Co-Cr-Mo components produced by direct metal laser sintering. Mater Sci Eng C [Internet]. 2015;48:263–9. Available from: http://dx.doi.org/10.1016/j.msec.2014.12.009

12. Schweiger J, Güth JF, Erdelt KJ, Edelhoff D, Schubert O. Internal porosities, retentive force, and survival of cobalt–chromium alloy clasps fabricated by

selective laser-sintering. J Prosthodont Res [Internet]. 2020;64(2):210–6. Available from: https://doi.org/10.1016/j.jpor.2019.07.006

13. Venkatesh KV, Nandini VV. Direct metal laser sintering: A digitised metal casting technology. J Indian Prosthodont Soc. 2013;13(4):389–92.

14. Soltanzadeh P, Suprono MS, Kattadiyil MT, Goodacre C, Gregorius W. An In Vitro Investigation of Accuracy and Fit of Conventional and CAD/CAM Removable Partial Denture Frameworks. J Prosthodont. 2019;28(5):547–55.

15. Takachi A., Fueki K, Murakanami, N., Ueno T, Inamochi Y, Wada J, Arai Y, Wakabayashi N. A systematic review of digital removable partial dentures. Part II: CAD/CAM framework, artificial teeth, and denture base. Journal of Prosthodontic Research. 2021;(65).

16. Bajunaid SO, Altwaim B, Alhassan M, Alammari R. The fit accuracy of removable partial denture metal frameworks using conventional and 3D printed techniques: An in vitro study. J Contemp Dent Pract. 2019;20(4):476–81.

17. Chen H, Li H, Zhao Y, Zhang X, Wang Y, Lyu P. Adaptation of removable partial denture frameworks fabricated by selective laser melting. J Prosthet Dent [Internet]. 2019;122(3):316–24. Available from: https://doi.org/10.1016/j.prosdent.2018.11.010

18. Bohnenkamp DM. Removable partial dentures: Clinical concepts. Dent Clin North Am [Internet]. 2014;58(1):69–89. Available from: http://dx.doi.org/10.1016/j.cden.2013.09.003

19. Al Jabbari YS. Physico-mechanical properties and prosthodontic applications of

Co-Cr dental alloys: A review of the literature. J Adv Prosthodont. 2014;6(2):138–45.

20. Ye H, Ning J, Li M, Niu L, Yang J, Sun Y, et al. Preliminary Clinical Application of Removable Partial Denture Frameworks Fabricated Using Computer-Aided Design and Rapid Prototyping Techniques. Int J Prosthodont. 2017;30(4):348–53.

21. Tregerman I, Renne W, Kelly A, Wilson D. Evaluation of removable partial denture frameworks fabricated using 3 different techniques. J Prosthet Dent [Internet]. 2019;122(4):390–5. Available from: https://doi.org/10.1016/j.prosdent.2018.10.013

22. Peng PW, Hsu CY, Huang HY, Chao JC, Lee WF. Trueness of removable partial denture frameworks additively manufactured with selective laser melting. J Prosthet Dent [Internet]. 2020;1–6. Available from: https://doi.org/10.1016/j.prosdent.2020.06.035

23. Tasaka A, Shimizu T, Kato Y, Okano H, Ida Y, Higuchi S, et al. Accuracy of removable partial denture framework fabricated by casting with a 3D printed pattern and selective laser sintering. J Prosthodont Res [Internet]. 2020;64(2):224–30. Available from: https://doi.org/10.1016/j.jpor.2019.07.009

24. Lee WF, Wang JC, Hsu CY, Peng PW. Microstructure, mechanical properties, and retentive forces of cobalt-chromium removable partial denture frameworks fabricated by selective laser melting followed by heat treatment. J Prosthet Dent [Internet]. 2020;1–7. Available from:

https://doi.org/10.1016/j.prosdent.2020.06.038

25. Ohkubo C, Sato Y, Nishiyama Y, Suzuki Y. Titanium removable denture based on a one-metal rehabilitation concept. Dent Mater J. 2017;36(5):517–23.

9. ANEXOS

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Removable partial denture alloys processed by laser-sintering technique

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Abstract: Removable partial dentures (RPDs) are traditionally made using a casting technique. New additive manufacturing processes based on laser sintering has been developed for quick fabrication of RPDs metal frameworks at low cost. The objective of this study was to characterize the mechanical, physical, and biocompatibility properties of RPD cobalt–chromium (Co–Cr) alloys produced by two laser-sintering systems and compare them to those prepared using traditional casting methods. The laser-sintered Co–Cr alloys were processed by the selective laser-sintering method (SLS) and the direct metal laser-sintering (DMLS) method using the Phenix system (L-1) and EOS system (L-2), respectively. L-1 and L-2 techniques were 8 and 3.5 times more precise than the casting (CC) technique ($p < 0.05$). Co–Cr alloys processed by L-1 and L-2 showed higher ($p < 0.05$) hardness (14–19%), yield strength (10–13%), and fatigue resistance (71–72%) compared to CC alloys. This was probably due to their smaller grain size and higher microstructural homogeneity. All Co–Cr alloys exhibited low porosity (2.1–3.3%); however, pore distribution was more homogenous in L-1 and L-2 alloys when compared to CC alloys. Both laser-sintered and cast alloys were biocompatible. In conclusion, laser-sintered alloys are more precise and present better mechanical and fatigue properties than cast alloys for RPDs. © 2017 Wiley Periodicals, Inc. J Biomed Mater Res Part B: Appl Biomater 00B: 000–000, 2017.

Key Words: laser-sintering, cobalt–chromium (Co–Cr), removable partial dentures, fatigue resistance, biocompatibility

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INTRODUCTION

Removable partial dentures (RPDs) are simple and cost-effective prostheses that can restore missing teeth in partially edentulous patients, and thus improving their quality of life.[1,2] This type of treatment has an important impact on the life of millions of patients in the world; indeed, over 13% of the adult population in North America and Europe wear RPDs.[1,3] RPD frameworks are commonly made of cobalt–chromium (Co–Cr) alloys because of their suitable cost and mechanical properties, and their excellent corrosion resistance and biocompatibility.[4]

RPD frameworks are traditionally fabricated using the casting (lost-wax) technique that has been used in dentistry for more than a century.[5,6] The casting technique is a very laborious manual process that involves making a wax replica of the object, making a mold of the object, and then cast the melted metal into the mold. Owing to its complexity, this technique is strongly influenced by the skill of the dental technician.[5,7] Moreover, producing RPDs by casting technique not only is time consuming and costly but may also generates low precision and ill-fitting frameworks.[7,8]

Different methods were introduced in the last few decades for fabricating RPD frameworks without using casting techniques.[6,9,10] A new additive manufacturing (AM) process based on laser-sintering has been developed for processing 3-D metal objects. The laser-sintering technique combines computer-aided design (CAD) of any products and their subsequent fabrication using a high-power laser that fuses metal powder in a layer-by-layer pattern.[5,6,10–12] The laser-sintering technique enables the fabrication of complex 3-D objects quickly with high precision (20 μm) and at low cost.[10–15]

Laser-sintering technology can be described using different terminologies, such as selective laser melting (SLM), selective laser-sintering (SLS), or direct metal laser-sintering (DMLS).[6,9,12,13] SLM involves full melting of the metal

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SYSTEMATIC REVIEW

Accuracy of CAD-CAM systems for removable partial denture framework fabrication: A systematic review

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ABSTRACT

Statement of problem. Removable partial dentures (RPDs) are traditionally made by casting, a complex, error-prone, and time-consuming process. Computer-aided design and computer-aided manufacturing (CAD-CAM) RPD systems may simplify the clinical steps and minimize errors; however, the accuracy of CAD-CAM RPD systems is unclear.

Purpose. The purpose of this systematic review was to determine whether CAD-CAM systems are accurate for the manufacturing of RPD frameworks.

Material and methods. A literature search was conducted through Medline-PubMed, Scopus, Lilacs, Web of Science, and Cochrane Library databases using specific keywords for articles published up to November 2019. Three reviewers obtained data and compared the results. All studies evaluated the framework accuracy or fit of prostheses fabricated with conventional and digital techniques.

Results. A total of 7 articles, 2 clinical studies, and 5 in vitro studies that complied with the inclusion criteria were evaluated. One in vitro study compared indirect (extraoral) and direct (intraoral) scanning for partially edentulous ridges and shows that digital scans were better than conventional impressions in terms of trueness. In the other studies included, although the frameworks analyzed had clinically acceptable discrepancies (<311 µm), the material influenced the fit. Polyetheretherketone (PEEK) showed better fit than traditional metal cast RPDs. Co-Cr alloy RPDs produced by rapid prototyping exhibited the highest discrepancies when produced by sintering laser melting.

Conclusions. The results show that the digital technique for RPD frameworks is accurate. In the studies included, the analyzed frameworks had clinically acceptable gaps, but the results were heterogeneous among studies because the articles used different measurement methods with small sample sizes. Few studies discussed the long-term clinical performance. The digital technique for RPD frameworks was accurate because the misfits and mismatches found in in vitro and clinical studies were within the acceptable clinical limit for RPDs. (J Prosthet Dent 2020;■:■-■)

Traditionally, removable partial dentures (RPDs) are made by casting from the manual waxing of a framework on a refractory cast.[1,2] However, in recent years, computer-aided design and computer-aided manufacturing (CAD-CAM) technology has been applied in the processing of dental prostheses, including RPDs.[3-6] The digital workflow has become popular for making RPD frameworks, by scanning[7] and planning the prosthesis. Sometimes the digital workflow is combined with the conventional lost wax technique.[8]

RPD frameworks can be made by subtractive or additive manufacturing. Depending on the manufacturing process, a definitive prosthesis can be made directly from the digital design or from a resin pattern which is subsequently cast.[9,10] Additive 3D printing techniques include stereolithography (SLA), digital

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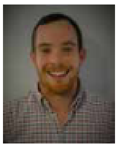

Dominic P Laverty

Matthew BM Thomas, Paul Clark and Liam D Addy

The Use of 3D Metal Printing (Direct Metal Laser Sintering) in Removable Prosthodontics

Abstract: The use of 3D printing is expanding and it is envisaged that it will have an increasing presence within dentistry. Having an appreciation and understanding of such technology is therefore paramount. It is currently used to produce a variety of dental objects/prostheses. This paper briefly looks at 3D printing in dentistry and specifically describes the use of the direct metal laser sintering 3D printing technique in the production of cobalt chromium removable prosthesis frameworks.

CPD/Clinical Relevance: Understanding the different technologies that can and are being used within the dental field is important, particularly as it is a rapidly changing field. Having an understanding of such technologies will allow practitioners to utilize such technologies appropriately in the management of their patients.

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Three-Dimensional (3D) printing is a process of making a 3D object from a digital file. The 3D object is created using an additive process whereby successive layers of material are placed until the object is created. These layers are thin horizontal 2D cross-sections of the eventual 3D object.[1]

It was Charles Hull in the early 1980s who invented 3D printing. He described the process of stereolithography or the 'printing' of successive layers of material on top of each other to create a 3D object.[2]

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The use of 3D printing is expanding, with the entire 3D printing industry currently worth around $700 million, and is expected to grow to an estimated $8.9 billion industry in the next 10 years.[3] Even NASA have used 3D printing to produce a fuel injector and plan to have a 3D printer on board their next space flight.[4]

This expansion in 3D printing is also being experienced within the medical field.[5] The current 3D printing industry is worth $11 million for medical applications but is projected to have exponential growth over the next 10 years to $1.9 billion.[6]

One of the advantages that 3D printing offers in its medical application is the ability to allow customization and personalization of medical products and equipment, at relatively low costs (as the cost of the first item is the same as the last)[5] and produced relatively quickly.[7] Hence, 3D printing is ideal for making one of a kind items at cost-effective prices.[5]

3D printing has been applied in with dentistry quick to embrace the use of this technology, particularly with regards to dental implant reconstructions.[8]

A number of published articles have described the use of 3D printing in medicine to produce cell cultures, blood vessels and vascular networks,[9] bandages,[10] bones,[11] ears,[12] exoskeletons,[13] windpipes[14] and corneas.[15] The use of 3D printing is also being investigated in repairing or replacing defective organs, such as kidneys, the heart and skin.[5]

In dentistry, 3D printing can produce metallic, polymer[16] and ceramic-based objects.[1] It has been used to produce a variety of dental objects including stereolithographic models, implant fixtures and components, removable prosthesis frameworks, fixed prosthesis and maxillofacial structures (hard and soft tissue).[17-26]

Denture frameworks have traditionally been produced using the lost wax technique and metal casting; however, 3D printing methods are now available. These offer quicker and more cost-efficient production with reduced recasting. Removable

Comparison of Fit of Dentures Fabricated by Traditional Techniques Versus CAD/CAM Technology

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Keywords
CAD/CAM; digital dentures; removable; injection molding; computer-aided design; denture bases; complete dentures; maxilla; maxillary arch; arch form; palate; palate depth; selective laser sintering; 3D printing; titanium.

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Abstract

Purpose: To compare the shrinkage of denture bases fabricated by three methods: CAD/CAM, compression molding, and injection molding. The effect of arch form and palate depth was also tested.

Materials and Methods: Nine titanium casts, representing combinations of tapered, ovoid, and square arch forms and shallow, medium, and deep palate depths, were fabricated using electron beam melting (EBM) technology. For each base fabrication method, three poly(vinyl siloxane) impressions were made from each cast, 27 dentures for each method. Compression-molded dentures were fabricated using Lucitone 199 poly methyl methacrylate (PMMA), and injection molded dentures with Ivobase's Hybrid Pink PMMA. For CAD/CAM, denture bases were designed and milled by Avadent using their Light PMMA. To quantify the space between the denture and the master cast, silicone duplicating material was placed in the intaglio of the dentures, the titanium master cast was seated under pressure, and the silicone was then trimmed and recovered. Three silicone measurements per denture were recorded, for a total of 243 measurements. Each silicone measurement was weighed and adjusted to the surface area of the respective arch, giving an average and standard deviation for each denture.

Results: Comparison of manufacturing methods showed a statistically significant difference ($p = 0.0001$). Using a ratio of the means, compression molding had on average 41% to 47% more space than injection molding and CAD/CAM. Comparison of arch/palate forms showed a statistically significant difference ($p = 0.023$), with shallow palate forms having more space with compression molding. The ovoid shallow form showed CAD/CAM and compression molding had more space than injection molding.

Conclusion: Overall, injection molding and CAD/CAM fabrication methods produced equally well-fitting dentures, with both having a better fit than compression molding. Shallow palates appear to be more affected by shrinkage than medium or deep palates. Shallow ovoid arch forms appear to benefit from the use of injection molding compared to CAD/CAM and compression molding.

Denture processes and materials have been slow to change over the last 100 years. The "age of thermoplastics," which began around 1910, saw the replacement of Vulcanite with polymethyl methacrylate (PMMA) used in combination with a compression molding technique.[1] This combination produced a volumetric shrinkage of approximately 7% and linear shrinkage of 0.9%, requiring additional modifications to counteract the shrinkage, such as high expansion stone and placement of a post-palatal seal.[2,3] Injection molding was introduced as a new processing technique in 1942 and was brought to market by Ivoclar in 1972.[4] In an effort to reduce the effects of shrinkage due to polymerization and heat, sprues were added to the denture and continuous pressure was applied to a reservoir of PMMA. This was a significant improvement, resulting in linear shrinkage being reduced to 0.65%.[3] More recently Ivoclar has introduced the Ivobase system, an injection molding process that uses a lower heat and claims to reduce volumetric shrinkage to 1.09%.

With the advent and spread of computer-aided design and computer assisted manufacturing (CAD/CAM) for fixed restorations during the 1980s, it was only a matter of time before this technology was applied to removable prosthodontics, and researchers began to solve the challenges involved with

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Original article

Clasp fabrication using one-process molding by repeated laser sintering and high-speed milling

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ABSTRACT

Purpose: A single machine platform that integrates repeated laser sintering and high-speed milling for one-process molding has been developed.

Methods: The Akers clasp was designed using the CAD system (DWOS Partial Frameworks, Dental Wings) and fabricated using repeated laser sintering and a high-speed milling machine (LUMEX Advance-25, Matsuura) with 50-μm Co-Cr particles (CAM clasp). As controls, cast clasps of the same forms were also prepared using conventional casting methods with a Co-Cr alloy and CP titanium Grade 3. After the surface roughness was measured, the gap distance between the clasps and the tooth die was assessed using the silicone film method. The initial retentive force and changes in retention up to 10,000 cycles were also measured. The data were analyzed using two-way ANOVA and Tukey's multiple comparison test ($\alpha = 0.05$).

Results: CAM clasps exhibited significantly smoother surfaces than those of cast Co-Cr and CP Ti clasps ($p < 0.05$). However, the gap distances of the CAM clasps were significantly greater than those of the cast clasps ($p < 0.05$). The retentive forces of both CAM and cast Co-Cr clasps were significantly higher than those of CP Ti clasps. ($p < 0.05$). The retention of CAM clasps demonstrated a constant or slight decrease from 1000 up to 10,000 cycles.

Conclusions: The CAM clasp made by repeated laser sintering and high-speed milling can be used effectively as an RPD component.

1. Introduction

Dental computer-aided designs and computer-aided machining (CAD/CAM) technology has rapidly improved from the beginning of the 21st century with the remarkable development of digital technology [1-4]. Using CAD/CAM, prostheses with higher mechanical properties and better fitness accuracy can be fabricated as compared with the conventional casting method [5-9]. The CAM system has mostly used metal and zirconia blocks in the milling process for fabricating prosthetic frameworks. However, the following disadvantages of the milling process have been identified: (1) it is not easy to manufacture complicated shapes and/or undercut areas, (2)

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An analytical model to design circumferential clasps for laser-sintered removable partial dentures

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Retention force
Stress

ABSTRACT

Objective. Clasps of removable partial dentures (RPDs) often suffer from plastic deformation and failure by fatigue; a common complication of RPDs. A new technology for processing metal frameworks for dental prostheses based on laser-sintering, which allows for precise fabrication of clasp geometry, has been recently developed. This study sought to propose a novel method for designing circumferential clasps for laser-sintered RPDs to avoid plastic deformation or fatigue failure.

Methods. An analytical model for designing clasps with semicircular cross-sections was derived based on mechanics. The Euler–Bernoulli elastic curved beam theory and Castigliano's energy method were used to relate the stress and undercut with the clasp length, cross-sectional radius, alloy properties, tooth type, and retention force. Finite element analysis (FEA) was conducted on a case study and the resultant tensile stress and undercut were compared with the analytical model predictions. Pull-out experiments were conducted on laser-sintered cobalt–chromium (Co–Cr) dental prostheses to validate the analytical model results.

Results. The proposed circumferential clasp design model yields results in good agreement with FEA and experiments. The results indicate that Co–Cr circumferential clasps in molars that are 13 mm long engaging undercuts of 0.25 mm should have a cross-section radius of 1.2 mm to provide a retention of 10 N and to avoid plastic deformation or fatigue failure. However, shorter circumferential clasps such as those in premolars present high stresses and cannot avoid plastic deformation or fatigue failure.

Significance. Laser-sintered Co–Cr circumferential clasps in molars are safe, whereas they are susceptible to failure in premolars.

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RESEARCH AND EDUCATION

Influence of build angulation on the mechanical properties of a direct-metal laser-sintered cobalt-chromium used for removable partial denture frameworks

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ABSTRACT

Statement of problem. Direct-metal laser-sintering (DMLS) technologies are being used to manufacture removable partial denture frameworks; however, the build parameters are not well documented.

Purpose. The purpose of this in vitro study was to investigate the impact of 3 different build angulations on a dental cobalt-chromium (Sint-Tech ST2724G) alloy by comparing the tensile properties and nanoindentation hardness. The null hypothesis was that no change would be found in the tensile properties of the different build angulation groups.

Material and methods. Dumbbell-shaped tensile specimens were produced by using stereolithographic models in accordance with American Society for Testing and Materials testing standard E8/E8M-16ae1. Specimens (n=10) were fabricated by using DMLS additive manufacturing with 3 different angulations (0, 45, and 90 degrees). Tensile testing was carried out to assess yield strength (0.2% permanent offset), elongation (%) at failure, and ultimate tensile strength (GPa). Scanning electron microscope (SEM) images were used to analyze the fracture surfaces. One 10×10×10 mm cube specimen at each orientation was prepared, and nanoindentation was used to determine hardness and elastic modulus. One-way ANOVA was used to evaluate the overall effects with interaction between groups and post hoc testing applied where the interaction was statistically significant (α=.05).

Results. The 45-degree build angulation resulted in the lowest mean elastic modulus of 213.3 GPa and the highest tensile strength of 1180.9 MPa. The 90-degree build angulation resulted in the highest mean elongation of 10.6% and the highest elastic modulus of 234.0 MPa. Within comparison of the different angulations indicated that various groups had statistically significant differences (P<.05). The SEM analysis indicated different fracture topography among the different build angles.

Conclusions. The cobalt-chromium dental alloy manufactured by DMLS produced favorable mechanical properties. The SEM analysis combined with the tensile test results suggest that the direction of the build angle in relation to the laser melt pattern does impact the mechanical properties of the alloy. (J Prosthet Dent 2020;■:■-■)

Direct-metal laser-sintering (DMLS) and selective laser melting (SLM) additive processing methods are being used to produce removable partial denture (RPD) frameworks.[1] The DMLS system is based on a layer-by-layer addition and subsequent laser-sintering of a metal powder.[2] The DMLS powder bed method used for dental applications has a material dispensing platform combined with a build platform controlled by a 3D computer-aided design software program.[1,3] The surface roughness of alloys produced through DMLS is reported to be influenced by the sintered surface orientation to the build direction, and the surface parallel to the build direction roughness was reported to be 12.6 µm compared with the parallel (18.2 µm).[4] Kajima et al[5]

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THE JOURNAL OF PROSTHETIC DENTISTRY

CLINICAL RESEARCH

Patient satisfaction with laser-sintered removable partial dentures: A crossover pilot clinical trial

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ABSTRACT

Statement of problem. Clinical data regarding newly introduced laser-sintered removable partial dentures (RPDs) are needed before this technique can be recommended. Currently, only a few clinical reports have been published, with no clinical studies.

Purpose. This clinical trial compared short-term satisfaction in patients wearing RPDs fabricated with conventional or computer-aided design and computer-aided manufacturing (CAD-CAM) laser-sintering technology.

Material and methods. Twelve participants with partial edentulism were enrolled in this pilot crossover double-blinded clinical trial. Participants were randomly assigned to wear cast or CAD-CAM laser-sintered RPDs for alternate periods of 30 days. The outcome of interest was patient satisfaction as measured using the McGill Denture Satisfaction Instrument. Assessments was conducted at 1, 2, and 4 weeks. The participant's preference in regard to the type of prosthesis was assessed at the final evaluation. The linear mixed effects regression models for repeated measures were used to analyze the data, using the intention-to-treat principle. To assess the robustness of potential, incomplete adherence, sensitivity analyses were conducted.

Results. Statistically significant differences were found in patients' satisfaction between the 2 methods of RPD fabrication. Participants were significantly more satisfied with laser-sintered prostheses than cast prostheses in regard to general satisfaction, ability to speak, ability to clean, comfort, ability to masticate, masticatory efficiency, and oral condition ($P<.05$). At the end of the study, 5 participants preferred the laser-sintered, 1 preferred the cast RPD, and 3 had no preference.

Conclusions. The use of CAD-CAM laser-sintering technology in the fabrication of removable partial dentures may lead to better outcomes in terms of patient satisfaction in the short term. The conclusion from this pilot study requires confirmation by a larger randomized controlled trial.

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Metal additive manufacturing technologies: literature review of current status and prosthodontic applications

Abstract

Objectives: To review the current metal-based additive manufacturing (AM) technologies, namely powder bed fusion (PBF) technologies, and their current prosthodontic applications. The PBF technologies reviewed are selective laser sintering (SLS), selective laser melting (SLM), and electron beam melting (EBM).

Materials and methods: The literature on metal AM technologies was considered, and the AM procedures and their current applications in prosthodontics were collated and described. Published articles about AM metal in dental care were searched (MEDLINE, EMBASE, EBSCO, and Web of Science). All studies related to the description, analysis, and evaluation of prosthodontic applications using metal AM technologies.

Results and conclusions: AM technologies are reliable for many applications in dentistry, including metal frameworks for removable partial dentures (RPDs), overdentures, tooth- and implant-supported fixed dental prostheses (FDPs), and metal frameworks for splinting implant impression abutments. However, further studies are needed in future to evaluate the accuracy, reproducibility, and clinical outcome throughout function of AM technologies.

Keywords: *3D printing, additive manufacturing technologies, electron beam melting, metal, selective laser melting, selective laser sintering, prosthodontics*

Introduction

Conventional casting and subtractive computer-aided manufacturing (CAM) technologies are the most common methods used by dentists to manufacture dental prosthetics.[1] CAM technologies typically refer to a computer numerically controlled (CNC) system, which controls power-driven machine tools. Under the direction of computer software, these tools mechanically remove material from a block form to achieve the desired framework.[2-4] Although these technologies are considered the gold standard for the fabrication of fixed dental prostheses (FDPs), subtractive technologies present a number of manufacturing limitations. These limitations include a considerable amount of wasted raw material (unused remnants of the milling block), the short running cycle of the milling tool due to the abrasive wear of milling, and the space limitations imposed by the size of the milling burs and the axis of the CNC machine, which in turn limit access to smaller areas of the milling block.[5-7]

Additive manufacturing (AM) procedures, in which a powder or liquid base material is built into a solid object, provide a promising alternative manufacturing method.[8,9] The American Society for Testing and Materials (ASTM International) has defined AM technology as "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing (SM) methodologies."[10] The industry standard computer-aided design (CAD) data file format is Standard Triangulation Language (STL), in which boundaries are represented by triangular facets.[11]

In 2008, the ASTM International Technical Committee F42 on AM technologies outlined seven AM categories: stereolithography (SLA), material jetting, material extrusion, binder jetting, powder bed fusion (PBF), sheet lamination, and direct energy deposition.[10] PBF technologies are most commonly used for 3D metal printing in dentistry. There are three types of PBF technologies: selective laser sintering (SLS), selective laser melting (SLM), and electron beam melting (EBM).[10]

Selective laser sintering (SLS)

In 1989, Carl Deckard, along with Joe Beaman, developed and patented SLS technology.[12,13] During this procedure, a high-powered laser (Nd:YAG laser) beam is focused onto a bed of powdered metal, which then fuses into a thin solid layer (20 to100 µm). Another layer of powder is then laid down, which becomes the next slice of the framework. The laser then fuses the top layer with the layer beneath. This process is repeated until the three-dimensional (3D) object is built (Fig 1).[14]

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Original article

Fitness and retentive force of cobalt-chromium alloy clasps fabricated with repeated laser sintering and milling

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ABSTRACT

Purpose: With computer-aided design and computer-aided manufacturing (CAD/CAM), the study was conducted to create a removable partial denture (RPD) framework using repeated laser sintering rather than milling and casting techniques. This study experimentally evaluated the CAM clasp and compared it to a conventional cast clasp.
Methods: After the tooth die was scanned, an Akers clasp was designed using CAD with and without 50 μm of digital relief on the occlusal surface of the tooth die. Cobalt-chromium (Co-Cr) alloy clasps were fabricated using repeated laser sintering (RLS) and milling as one process simultaneously (hybrid manufacturing; HM). The surface roughness of the rest region, gap distances between clasp and tooth die, initial retentive forces, and changes of retentive forces up to 10,000 insertion/removal cycles were measured before and after heat treatment. The HM clasp was compared to the cast clasp and the clasp made by repeated laser sintering only without a milling process.
Results: The HM clasp surface was smoother than those of cast and RLS clasps. With the digital relief, the fitness accuracy of the HM clasp improved. The retentive forces of the HM clasps with relief and after heat treatment were significantly greater than for the cast clasp. HM clasps demonstrated a constant or slight decrease of retention up to 10,000 cycles.
Conclusions: HM clasp exhibited better fitness accuracy and retentive forces. The possibility of clinically using HM clasps as well as conventional cast clasps can be suggested.

1. Introduction

With computer-aided design and computer-aided manufacturing (CAD/CAM), the study was conducted to use repeated laser sintering rather than milling a framework from an alloy disk or milling patterns and then casting to fabricate removable partial denture (RPD) frameworks [1–9]. The advantages of repeated laser sintering as compared to milling and casting techniques are as follows: (1) near net shape forming can be achieved, (2) chips do not occur while cutting, (3) irregular shapes—clasps, connectors, and undercut areas—can be formed, (4) worn cutting tools cannot cause imprecision, (5) many frameworks can be simultaneously fabricated, (6) all processes are completely automatic, and (7) the cost is low [10,11].

In 2008, Tiossi et al. [12] examined the mechanical properties of laser-sintered as compared to conventionally cast cobalt-chromium (Co-Cr) and titanium alloys [12]. The laser-sintered Co-Cr and titanium alloys demonstrated higher tensile strengths and proof stresses than those of cast alloys, although there were no significant differences in the elongation and elastic modulus between them. These phenomena would be caused by laser-sintered alloys composed of fine structures using fine alloy powders. Almufleh et al. [13] reported on patient satisfaction with laser-sintered RPDs versus conventional cast RPDs using a crossover study [13]. Although it was short clinical observation, laser-sintered RPDs might lead to better patient satisfaction than conventional RPDs.

The limits and problems of conventional repeated laser sintering are surfaces that are too rough and, consequently, worsening fitness accuracy [14–16]. To make the surface smooth

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Structural characterization of biomedical Co–Cr–Mo components produced by direct metal laser sintering

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ABSTRACT

Direct metal laser sintering (DMLS) is a technique to manufacture complex functional mechanical parts from a computer-aided design (CAD) model. Usually, the mechanical components produced by this procedure show higher residual porosity and poorer mechanical properties than those obtained by conventional manufacturing techniques.

In this work, a Co–Cr–Mo alloy produced by DMLS with a composition suitable for biomedical applications was submitted to hardness measurements and structural characterization. The alloy showed a hardness value remarkably higher than those commonly obtained for the same cast or wrought alloys. In order to clarify the origin of this unexpected result, the sample microstructure was investigated by X-ray diffraction (XRD), electron microscopy (SEM and TEM) and energy dispersive microanalysis (EDX). For the first time, a homogeneous microstructure comprised of an intricate network of thin ε (hcp)-lamellae distributed inside a γ (fcc) phase was observed. The ε-lamellae grown on the $\{111\}_\gamma$ planes limit the dislocation slip inside the γ (fcc) phase, causing the measured hardness increase. The results suggest possible innovative applications of the DMLS technique to the production of mechanical parts in the medical and dental fields.

1. Introduction

Nowadays, a new class of manufacturing methods is becoming increasingly important for the production of biomedical devices. Among them, novel methods based on additive manufacturing (AM), assisted by computer-aided design/computer-aided manufacturing (CAD/CAM), allow the production of intricate mechanical parts [1–4].

Direct metal laser sintering (DMLS) is an AM process that uses the heat of a solid state laser to sinter metal powder particles [5]. In this case, a distribution mechanism pre-places successive layers of powder on a suitable substrate, while a laser beam controlled by a scanning system locally sinters the powder in accordance with the CAD model [6]. This technology, like other AM procedures, is highly rewarding in medicine where a high degree of personalization is required [7–9]. Prosthetic applications are particularly well suited for processing by means of DMLS due to their complex geometry, low volume and strong individualization [10]. Furthermore, the manufacturing of multiple unique parts in a single production run enables extensive customization with a strong reduction of manual operation leading to higher repeatability and good savings in money and delivery times.

Cobalt-based alloys were extensively used in cast and hard facing forms over the past twenty years because of their corrosion and wear resistance, biocompatibility and excellent strength and toughness at high temperature [11]. Typical applications of the Co-based alloys involved both the biomedical and the metallurgical fields [12,13].

From a structural point of view, cobalt is characterized by a ε (hcp) low temperature phase and a γ (fcc) phase at higher temperature. Addition of chromium improves the corrosion and the oxidation resistance of the alloy, as well as its hardness, ductility and wear resistance through carbide formation. Molybdenum improves the corrosion resistance and acts as a solid-solution strengthener by forming the Co_3Mo (hcp) intermetallic compound [14].

Cast alloys with a Cr content ranging from 19 wt.% to 30 wt.% and a Mo content in the range 5–10 wt.% were considered for biomedical applications and for many years these compositions were used to produce medical implants such as hips, knees, ankles and bone plates [15].

Although in the past few years, several AM techniques were applied to produce biocompatible Co-based alloys, only in few cases a deep microstructural characterization of the sintered components were

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Original article

Internal porosities, retentive force, and survival of cobalt–chromium alloy clasps fabricated by selective laser-sintering

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ABSTRACT

Purpose: The purpose of this study was to evaluate internal porosities, retentive force values and survival of cobalt–chromium (Co–Cr) alloy clasps fabricated by direct metal laser-sintering (DMLS) and compare them to conventionally cast clasps.

Methods: Embrasure clasps were digitally designed fitting teeth 35 and 36 on identical metal models (N = 32). Sixteen clasps were fabricated using DMLS (group DMLS) and another sixteen clasps were additively manufactured from wax and then cast from a Co–Cr alloy (group CAST). Internal porosities were examined using micro-focus X-ray (micro-CT) and analyzed applying Kolmogorov–Smirnov test, Mann–Whitney test, and T test (significance level: $p < 0.050$). A universal testing machine was used to determine the retentive force values at baseline and after 1095, 5475, 10,950 and 65,000 cycles of simulated aging. Data were analyzed employing Kolmogorov–Smirnov test, one-way ANOVA, and Scheffé's post-hoc test (significance level: $p < 0.050$). Survival was estimated for 65,000 cycles of artificial aging using Kaplan–Meier analysis.

Results: Micro-CT analysis revealed a higher prevalence ($p < 0.001$), but a more homogeneous size and a significantly smaller mean ($p = 0.009$) and total volume ($p < 0.001$) of internal porosities for group DMLS. The groups showed mean initial retentive force values of 13.57 N (CAST) and 15.74 N (DMLS), which significantly declined over aging for group CAST ($p = 0.003$), but not for group DMLS ($p = 0.107$). Survival was considerably higher for group DMLS (93.8%) than for group CAST (43.8%) after 65,000 cycles of aging.

Conclusions: Clasps made by laser-sintering could be an alternative to conventional cast clasps for the fabrication of removable partial denture frameworks.

1. Introduction

Dentist Dr. F.E. Roach noted in 1930 that "[. . .] the clasp is the oldest and, [. . .] still is, and probably will continue to be, the most practical and popular means of anchoring partial dentures of the removable type" [1]. This statement is as topical in 2019 as it was almost a hundred years ago. Despite considerable progress in dental prophylaxis and modern operative, restorative, prosthetic, and implant dentistry, the removable partial denture (RPD) continues to be a reliable treatment option for a large percentage of patients. Due to increasing average life expectancy and decreasing tooth loss, requirements will tend to change from removable full dentures to RPDs, and demand is expected to increase in the future [2–4].

Being cost-effective, highly versatile [4], and commonly satisfactory to the patient regarding the overall treatment outcome [5], the RPD must be considered better than its general reputation. On the downside, there are inherent drawbacks in terms of aesthetics or biomechanical problems such as non-physiological loading [6], sensitivity and wear of abutment teeth caused by the denture [5], but also an increased susceptibility to root caries and periodontal health issues [7]. Common technical complications such as deformation and fatigue fracture of RPD clasps result in loss of retention and function and cause the need for extensive reworking and additional expenses [8,9]. To avoid adverse events, diligent treatment planning and procedure, proper aftercare, optimum hygiene, but equally important, selection of a sophisticated technique and adequate materials are fundamental preconditions for long-term success.

Co–Cr alloys are a material of choice for the fabrication of RPD frameworks [10]. They have been widely used in dental applications combining excellent biocompatibility, favorable physicochemical properties [11], and low expenses. Nowadays RPD framework, that is, clasps, connectors, and support elements, is still commonly fabricated using analogue casting methods, in particular the lost-wax technique.

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REVIEW ARTICLE

Direct Metal Laser Sintering: A Digitised Metal Casting Technology

K. Vijay Venkatesh · V. Vidyashree Nandini

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Abstract Dental technology is undergoing advancements at a fast pace and technology is being imported from various other fields. One such imported technology is direct metal laser sintering technology for casting metal crowns. This article will discuss the process of laser sintering for making metal crowns and fixed partial dentures with a understanding of their pros and cons.

Keywords Metal laser sintering · 3D printing technology · Laser sintered crowns

Introduction

Metal casting technology has been recognized in industries and arts for more than a century. Metal casting has had its origin in ancient China/Egypt, where the idea of making a wax replica, surrounding this replica with an investment material, letting this harden, then melting wax and burning out the wax to produce an intricate and accurate mold was conceived. The next step involved is melting the metal and pouring it into the cavity. In the literature, Dr. Swasey (1890) was the first to introduce a technique of making solid gold inlay. Martin (1891) was the first to use wax for making gold inlays. Dr. Philbrook (1896) introduced pressure casting method of producing gold inlays. It was about 10 years later Dr. Taggart (1907) presented a paper before the New York Odontological Group, in which he discussed his casting technique and machine. Taggart's success was mostly due to his improved casting machine, since his casting technique was not original; the idea of using wax to form the pattern was that of Martin (1891), and using pressure to cast the alloy was that of Philbrook (1896). Since then, casting technology has come a long way in producing accurate castings.

Casting technology is undergoing a radical shift and a process of industrialization is taking place in dentistry like in all other industries. Computer-assisted design (CAD)/CAM milling is familiar ground for dentists by now. This innovation was followed by scanning (digital impression concept) that emerged as a consequence of technology and equipment from other industries are being adapted for use in dentistry. The use of digital dental technology is on the rise and manufacturing processes are being automated. Dental restorations that have long been conventionally produced from metal through the use of casting techniques is getting automated; this technique is a direct import from 3D printing and rapid prototyping technologies used in general manufacturing.

CAM milling technology is often referred to as subtractive process, as milling involves taking a block of material and cutting away everything that is not necessary until the final restoration emerges. In contrast, additive processes involve adding material layer by layer to build the final product. Basically four different 3D printing technologies (additive process) are being used in dental industry: stereo lithography apparatus, digital light projection, jet and direct metal laser sintering (DLMS or DMLS or just MLS) [1]. Each system varies in the materials available, how these materials are solidified and how they can be used.

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An In Vitro Investigation of Accuracy and Fit of Conventional and CAD/CAM Removable Partial Denture Frameworks

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Keywords
CAD/CAM; fit; 3D printing; accuracy; removable partial denture.

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Abstract

Purpose: To evaluate the overall accuracy and fit of conventional versus computer-aided design/computer-aided manufactured (CAD/CAM) removable partial denture (RPD) frameworks based on standard tessellation language (STL) data analysis, and to evaluate the accuracy and fit of each component of the RPD framework.
Materials and Methods: A maxillary metal framework was designed for a Kennedy class III Modification I arch. The master model was scanned and used to compare the fit and accuracy of RPD frameworks. Forty impressions (conventional and digital) of the master cast were made and divided into 4 groups based on fabrication method: group I, lost-wax technique (conventional technique), group II, CAD-printing, group III, CAD-printing from stone cast, and group IV, lost-wax technique from resin-printed model. RPD frameworks were fabricated in cobalt-chromium alloy. All frameworks were scanned, and the gap distance between the framework and scanned master model was measured at 8 locations. Color mapping was conducted using comprehensive metrology software. Data were statistically analyzed using the Kruskall-Wallis test, followed by the Bonferroni method for pairwise comparisons ($\alpha = 0.05$).
Results: Color mapping revealed distinct discrepancies in major connectors among the groups. When compared to 3D-printed frameworks, conventional cast frameworks fabricated using dental stone or printed resin models revealed significantly better fit ($p < 0.05$) particularly in the major connectors and guide plates. The biggest gap (0.33 mm $\pm$ 0.20 mm) was observed with the anterior strap of the major connector with the printed frameworks (groups II and III). The method of fabrication did not affect the adaptation of the rests or reciprocation plates.
Conclusions: Although both conventional and 3D-printing methods of framework fabrication revealed clinically acceptable adaptation, the conventional cast RPD groups revealed better overall fit and accuracy.

Intimate contact between the metal framework and the abutment teeth, along with properly extended and well-adapted denture bases to the supporting mucosa provide the support, stability, and retention required for removable partial dentures (RPD).[1] Traditionally, RPD design involved the fabrication of stone casts, evaluation and geometric characterization of the tooth and soft tissues relative to the path of placement, and careful fabrication of the RPD framework using a direct waxing method.[2] However, in recent years, computer-aided design/computer-aided manufacturing (CAD/CAM) has gained popularity for the fabrication of various dental restorations.[3] The CAD/CAM technique for the fabrication of RPD frameworks began with the aid of additive manufacturing technologies. In 2004, Williams et al designed and printed a resin RPD framework using CAD/CAM technology.[1] The resin framework was then cast into a metal framework using the lost-wax technique.[1] Later, the authors reported a technique where an RPD framework was designed and fabricated using the CAD-printing technique.[4] Using this technique, RPD frameworks, made from cobalt-chromium (Co-Cr) alloy were directly printed.[5]

Regarding accuracy, studies have shown that digital impressions using intraoral scanners are comparable to impressions made using vinyl polysiloxane (VPS) impression materials.[6-10] The advantage of virtually planning and designing fixed and removable prostheses is that specific geometric analysis tools enable the dentist or laboratory technician to create designs with

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Review article

A systematic review of digital removable partial dentures. Part II: CAD/CAM framework, artificial teeth, and denture base

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Abstract

Purpose: This study comprehensively reviewed the current status of the digital workflow of removable partial dentures (RPDs) and summarized information about the fabrication methods and material properties of the dental framework, artificial teeth, and denture base.

Study selection: We performed a systematic review of the literature published in online databases from January 1980 to April 2020 regarding RPD fabrication and materials used in the related digital technology. We selected eligible articles, retrieved information regarding digital RPDs, and conducted qualitative/quantitative analyses. In this paper, the computer-aided design/computer-aided manufacturing (CAD/CAM) framework, artificial teeth, and denture base materials are reported.

*Results:*A variety of materials, such as cobalt-chromium alloy, titanium, zirconia, and polyether ether ketone, are used for dental CAD/CAM frameworks. The mechanical strength of the metal materials used for the CAD/CAM framework was superior to that of the cast framework. However, the fitness and surface roughness of the framework and clasp fabricated using a selective laser melting (SLM) method were not superior to those obtained via cast fabrication. Most material properties and the surface roughness of poly methyl methacrylate (PMMA) discs used for digital RPDs were superior to those of heat-cured PMMA.

*Conclusions:*The use of a CAD/CAM framework and PMMA disc for digital RPDs offers numerous advantages over conventional RPDs. However, technical challenges regarding the accuracy and durability of adhesion between the framework and denture base remain to be solved. In digital fabrication, human technical factors influence the quality of the framework.

Keywords: *Digital dentistry, CAD/CAM framework, Denture base resin, Artificial teeth, Removable partial denture*

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1. Introduction

Given a rapid increase in the elderly population in developed countries, prosthetic treatments with removable dentures to replace missing teeth will be increasingly relevant in a future super-aged society [1, 2]. In fact, the Survey of Dental Diseases conducted in Japan in 2016 reported that in the elderly population over 65 years old, 81 of 100 individuals wear removable dentures (53 removable partial dentures [RPDs], 28 complete dentures) [3]. This suggests that the future demand for removable dentures for the elderly will increase.

Recently, the clinical application of digital technology has rapidly expanded to the broad field of dental practice [4, 5]. In prosthetic treatment with removable dentures, computer-aided design and manufacturing (CAD/CAM) technology is commercially used to fabricate complete dentures [6, 7] and frameworks for RPDs [8-12]. However, most removable dentures in Japan are fabricated using conventional methods.

Articles on the dental application of digital technology in removable prosthodontics are being increasingly published [13]. Previous review papers related to digital RPDs focused on methods for fabricating metal frameworks [14-18]. However, there have been no review papers that have comprehensively collected articles on the properties of the materials used for frameworks, denture bases, and artificial teeth, and integrated the data and conducted a quantitative analysis. Therefore, we conducted a systematic review with an aim of collecting evidence from clinical studies, case reports, and basic studies on materials and fabrication methods used for producing digital RPDs to identify the advantages of digital RPDs over conventionally fabricated RPDs and to highlight challenges to the extension of digital RPD applications [19].

In the first part of this systematic review, we discuss a case report published in 2019 that introduced a clasp-retained RPD fabricated through a full-digital workflow, without using a gypsum definitive cast. Intraoral scanners (IOSs) were used for taking digital impressions and for maxillomandibular relationship recording in the fabrication of digital RPDs. However, most of these cases were Kennedy Class III/IV partially edentulous arches with several missing teeth.

Future challenges to expanding the application of digital RPDs in terms of impression-taking and maxillomandibular relationship recording are as follows: development of impression methods around the border of the denture base, development of an algorithm to adjust to the pressure displacement of the mucosa in denture-bearing areas, and development of methods for maxillomandibular relationship recording in cases without occlusal support.

In the second part of the systematic review, we describe the fabrication methods and material properties relevant to the framework, denture base,

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The Fit Accuracy of Removable Partial Denture Metal Frameworks Using Conventional and 3D Printed Techniques: An *In Vitro* Study

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Abstract

Aim: To evaluate the accuracy of removable partial denture (RPD) metal frameworks fabricated by the conventional lost-wax (CLW) technique and those made by the selective laser melting (SLM).

Materials and methods: A dentoform of a mandibular Kennedy class III, modification 1 dental arch were surveyed, and rest seats were prepared on the abutment teeth. The dentoform was then duplicated into a metal die which was used as a reference model. Thirty RPD metal frameworks were fabricated by two techniques; fifteen for each technique. Polyvinyl siloxane (PVS) impression material was painted on the intaglio surface of the rests of each framework which is then seated on the reference die. PVS specimens that represent the gap under the rest were measured in four zones: buccal, lingual, marginal and central by a single examiner using a digital microscope at 50x in micrometers.

Results: Comparison between the two techniques for each abutment tooth revealed that the CLW technique had better fit in one tooth, while the SLM technique showed a better fit in two teeth.

Regarding the edentulous span length within the SLM technique, the long edentulous span had a significantly better fit. When comparing the four measured rest zones, it was found that in the CLW technique group, the marginal zone had the highest fit accuracy while the lingual zone showed the lowest fit accuracy. In the SLM group, the central zone had the best fit and the buccal zone had the worst fit.

Conclusion: RPD frameworks fabricated using the SLM technique showed better fit accuracy than those made by the CLW technique, however, the difference was not statistically significant.

Clinical significance: SLM is a promising technique for the fabrication of RPD frameworks in routine clinical practice.

Keywords: Fit accuracy, Laboratory research, Lost-wax technique, Removable partial denture framework, Selective laser melting laboratory research.

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Introduction

Nowadays, the improvement in oral health maintenance resulted in a fewer number of missing teeth which led to a greater need to treat partially edentulous as compared to completely edentulous patients.[1,2]

Replacement of the missing teeth and their associated structures is essential to restore masticatory function, satisfy esthetics and phonetics, and to prevent unwanted movement of the opposing or the adjacent teeth (supra eruption/drifting).[3]

Some clinical situations would necessitate the use of a RPD or prosthesis. These include but not limited to cases of long edentulous spans, lost or severely resorbed residual ridges and absence of posterior abutments. Moreover, some patients are not willing to undergo surgery for the placement of endosseous implants, while others do not want their sound teeth to be prepared as abutments for a fixed partial prosthesis.

Additionally, some people have financial limitations and are unable to afford more expensive treatment options.[3] In such cases, a removable partial prosthesis is a cost-effective treatment modality and despite the advancement in the other approaches for tooth replacement, it will still be an important treatment option.[1,4]

For more than 70 years, the primary method of RPD metal framework fabrication was the CLW technique.[5] However, this technique involves many laboratory procedures which are susceptible to accumulative human errors.[6] Therefore, a significant need exists to evaluate new RPD framework materials, design and fabrication technologies,[7] and many patients will require replacement of missing teeth. Although current treatment options also include fixed partial dentures and implants, RPDs At the beginning of the1970s, there was an evolution in digital dentistry through the development of computer-aided design and computer-aided manufacturing (CAD/CAM) technology. Until the early 1980s, subtractive manufacturing was the basic assembly method.[5] Recently, additive manufacturing was introduced to the dental field with various techniques. These include selective laser sintering (SLS) for non-metallic materials (i.e., ceramic or polymers) and selective laser melting (SLM) technique for metallic alloys.[5,8]

SLM is a material-addition technique in which the successive layers are created using a high energy laser beam that selectively

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RESEARCH AND EDUCATION

Adaptation of removable partial denture frameworks fabricated by selective laser melting

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ABSTRACT

Statement of problem. Selective laser melting (SLM) is a novel 3-dimensional (3D) printing technology that can directly form the metal frameworks of removable partial dentures. The adaptation of SLM frameworks has not been thoroughly evaluated.

Purpose. The purpose of this in vitro study was to evaluate the tissue surface adaptation of removable partial denture frameworks fabricated by an SLM technique.

Material and methods. Four types of maxillary partial edentulous resin models were custom made: bilateral second premolars and molars missing, bilateral premolars and first molars missing, all teeth missing except 2 canines, and 2 central incisors missing. According to these dentition-defect patterns, 4 types (I, II, III, and IV) of virtual removable partial denture frameworks were designed, and an SLM printer was used for 3D printing using cobalt-chromium (Co-Cr) alloys (repeated 3 times). As a control, refractory casts duplicated from the resin models were used to fabricate denture frameworks by the lost-wax casting technique. Average gaps and maximum gaps between frameworks and models were measured using the silicone impression material. Two-way ANOVA was used to determine the influence of production methods and design types on the gaps (α=.05).

Results. The 2-way ANOVA showed that average gaps were significantly influenced by the production methods and design types, as well as their interactions (P<.001). With design Types I and II, the average gaps of the SLM-printed frameworks were larger than those of the cast ones (P<.001). However, no such differences were found for design Type III, P=.325, or IV, P=.862.

Conclusions. SLM-printed frameworks achieved an acceptable adaptation. However, among frameworks with a large span and relatively more retainers and clasps, the adaptation of those made by the precision casting technique was slightly better than that of those printed by the SLM technique. (J Prosthet Dent 2019;122:316-24)

Dentition defects are common among elderly people, but the denture restoration rate is rather low.[1-3] Removable partial dentures are suitable prostheses for a variety of dentition defects, with advantages[4] such as minimal tooth preparation, ease of cleaning and repair, and low cost. Removable partial dentures can improve patients' quality of life in a straightforward and effective manner[5] and have a long service life.[6]

Removable partial denture frameworks have been mainly produced by precision casting technology, usually from a nonprecious metal such as a cobalt-chromium (Co-Cr) alloy. The casting shrinkage of Co-Cr alloys is relatively large and requires expansion of the investment materials to compensate.[7]

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Removable Partial Dentures

Clinical Concepts

David M. Bohnenkamp, DDS, MS

KEYWORDS

- Classification systems • Clasp assemblies • Computer-aided design
- Laboratory work authorization • Partially edentulous patient
- Removable partial denture

KEY POINTS

- Although classic theories and rules for removable partial dentures (RPDs) designs have been presented and should be followed, excellent clinical care for partially edentulous patients may also be achieved with computer-aided design (CAD)/computer-aided manufacturing (CAM) technology and unique blended designs.
- These nontraditional RPD designs and fabrication methods provide for improved fit, function, and esthetics using CAD software, composite resin for contours and morphology of abutment teeth, metal support structures for long edentulous spans and collapsed occlusal vertical dimensions, and flexible nylon thermoplastic material for metal-supported clasp assemblies.

RATIONALE AND INDICATIONS FOR RPDS

The primary reason often cited for the fabrication and delivery of an RPD for dental patients is the replacement of missing teeth in a cost-effective manner.[1] Most clinicians also choose an RPD for a partially edentulous patient if they need to restore lost residual ridge, achieve appropriate esthetics, increase masticatory efficiency, and improve phonetics but are unable to do so with dental implants or fixed partial dentures due to financial constraints or patient desires (**Figs. 1–4**).

In certain situations, RPDs are indicated as a choice of treatment of partially edentulous patients when the length of the edentulous span contraindicates a fixed partial denture, there is a need for residual ridge support for mastication, or a patient has a guarded prognosis for their periodontal condition (**Figs. 5–8**).[2] Other indications for RPDs are excessive loss of residual ridge, a requirement for a denture base flange, obtaining proper tooth position not achievable due to the biomechanics of dental

The author has nothing to disclose.

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Physico-mechanical properties and prosthodontic applications of Co-Cr dental alloys: a review of the literature

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Cobalt-Chromium (Co-Cr) alloys are classified as predominantly base-metal alloys and are widely known for their biomedical applications in the orthopedic and dental fields. In dentistry, Co-Cr alloys are commonly used for the fabrication of metallic frameworks of removable partial dentures and recently have been used as metallic substructures for the fabrication of porcelain-fused-to-metal restorations and implant frameworks. The increased worldwide interest in utilizing Co-Cr alloys for dental applications is related to their low cost and adequate physico-mechanical properties. Additionally, among base-metal alloys, Co-Cr alloys are used more frequently in many countries to replace Nickel-Chromium (Ni-Cr) alloys. This is mainly due to the increased concern regarding the toxic effects of Ni on the human body when alloys containing Ni are exposed to the oral cavity. This review article describes dental applications, metallurgical characterization, and physico-mechanical properties of Co-Cr alloys and also addresses their clinical and laboratory behavior in relation to those properties. ***[J Adv Prosthodont 2014;6:138-45]***

KEY WORDS: Co-Cr alloys; Base metal alloys; Physical properties; Mechanical properties; Metallurgical characterization

INTRODUCTION

The application of predominantly base-metal alloys in removable and fixed prosthodontics has become more popular since the 1980s, due to the increasing cost of noble metals, especially after the global financial crisis of 2008. Cobalt-Chromium (Co-Cr) alloys are among the best-known base metal alloys in dentistry with various and successful clinical applications.

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Most of the Co-Cr alloys currently used in industrial and biomedical fields evolved from the work of Elwood Haynes at the turn of previous century. Initially, he demonstrated that the binary Co-Cr alloy possesses high strength and resists stain, and he subsequently identified molybdenum (Mo) and tungsten (W) as powerful strengthening agents for these alloys. Because of their stainless nature and permanent 'star-like' luster, Haynes named them *Stellite alloys*, based on the Latin word *Stella*, which means 'star'.[1]

Co-Cr alloys can be generally described as alloys that have high strength, are heat-resistant and non-magnetic, and have favorable resistance to wear, corrosion, and tarnish.[1] They possess excellent biocompatibility[2,3] and corrosion and tarnish resistance,[4,5] while the high modulus of elasticity (E) provides the requisite strength and rigidity without the need for heavy cross-sections, thus reducing the weight of metal substructures. Currently, biomedical applications of Co-Cr alloys are mainly related to the fabrication of orthopedic prostheses for knee, shoulder, and hip replacement as well as for use as fixation devices for fractured bones (joint endoprostheses).[6]

The first known dental application of Co-Cr alloys

Preliminary Clinical Application of Removable Partial Denture Frameworks Fabricated Using Computer-Aided Design and Rapid Prototyping Techniques

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Purpose: The aim of this study was to explore the application of computer-aided design and rapid prototyping (CAD/RP) for removable partial denture (RPD) frameworks and evaluate the fitness of the technique for clinical application. ***Materials and Methods:*** Three-dimensional (3D) images of dentition defects were obtained using a lab scanner. The RPD frameworks were designed using commercial dental software and manufactured using selective laser melting (SLM). A total of 15 cases of RPD prostheses were selected, wherein each patient received two types of RPD frameworks, prepared by CAD/RP and investment casting. Primary evaluation of the CAD/RP framework was performed by visual inspection. The gap between the occlusal rest and the relevant rest seat was then replaced using silicone, and the specimens were observed and measured. Paired *t* test was used to compare the average thickness and distributed thickness between the CAD/RP and investment casting frameworks. Analysis of variance test was used to compare the difference in thickness among different zones. ***Results:*** The RPD framework was designed and directly manufactured using the SLM technique. CAD/RP frameworks may meet the clinical requirements with satisfactory retention and stability and no undesired rotation. Although the average gap between the occlusal rest and the corresponding rest seat of the CAD/RP frameworks was slightly larger than that of the investment casting frameworks ($P < .05$), it was acceptable for clinical application. ***Conclusion:*** RPD frameworks can be designed and fabricated directly using digital techniques with acceptable results in clinical application. *Int J Prosthodont 2017;30:348–353. doi: 10.11607/ijp.5270*

Removable partial denture (RPD) is an important conventional treatment method for partially edentulous arches, one of the most common diseases in prosthodontics. Computer-aided design and computer-aided manufacturing (CAD/CAM) techniques have been applied in the field of dentistry for the past three decades. Development of CAD/CAM techniques in the area of RPD was slow in the earlier years because there was no specific software to support it and the CAM techniques relied exclusively on subtractive methods. The current dental CAD/CAM systems are not applicable for fabricating complex metal RPD frameworks because the techniques used therein are subtractive manufacturing methods such as grinding, cutting, and milling processes that may cause deformation or breaking at thin or narrow areas during manufacturing. In recent years, rapid prototyping (RP), an additive material manufacturing technique, has developed rapidly in dentistry to fabricate frameworks of different prostheses, including RPDs. Commonly used RP techniques are stereolithography (SLA), three-dimensional printing (3DP), selective laser sintering (SLS), selective laser melting (SLM), and fused deposition modeling (FDM).[1] RP has gradually been introduced in digital manufacturing research for RPDs as it can fabricate products of any shape

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CLINICAL RESEARCH

Evaluation of removable partial denture frameworks fabricated using 3 different techniques

Irving Tregerman, DDS,[a] Walter Renne, DMD,[b] Abigail Kelly, MS,[c] and Dalton Wilson, DDS[d]

ABSTRACT

Statement of problem. Rapid advancements in computer-aided design and computer-aided manufacturing (CAD-CAM) have opened new pathways in the fabrication of removable partial dentures (RPDs) through additive and subtractive processes. Questions remain whether the digital pathway is an acceptable one compared with conventional analog or combined analog and digital pathways.

Purpose. The purpose of this clinical study was to determine the quality of RPD frameworks fabricated using 3 different fabrication methods: analog, combined analog-digital, and digital.

Material and methods. Three RPD frameworks were fabricated for each of the 9 participants using each of the 3 techniques. Of the 9 participants enrolled, 4 were of Kennedy class I, 3 were of Kennedy class II, and 2 were of Kennedy class III. The first technique was completely analog: a physical impression was made using polyvinyl siloxane, stone casts were made, a survey was performed, and a laboratory technician waxed and cast the RPD framework. The combined analog-digital workflow had the analog steps, but the stone cast was scanned with a laboratory scanner to generate a digital cast. The 3Shape CAD software was then used to design a digital RPD, which was fabricated from a cobalt-chroumum alloy by selective laser melting. The third technique was completely digital: an intraoral digital scanner was used to make a definitive scan, which was sent to the 3Shape software for digitally designing the RPD framework and subsequent selective laser melting for fabrication. For all frameworks in the same participant, the same design was used for consistency. The evaluation consisted of a yes/no survey with 7 framework-related parameters and was completed by 5 clinicians. For statistics, an overall *P* value was calculated using a chi-squared test to determine any difference among the groups (α=.05).

Results. Seven of the 9 participants received the framework fabricated using the digital pathway as their definitive prosthesis. The completely digital method was significantly better than the traditional method of analog fabrication (P<.001). Intraoral scanning was also significantly better than the combined method of fabrication (P<.001). The completely analog method was better than the combined method of framework fabrication (P=.008).

Conclusions. Within the limitations of this clinical study, it was concluded that the combined analog-digital pathway of RPD fabrication was the least clinically acceptable one as determined by 5 calibrated clinicians using a yes/no questionnaire, whereas the completely digital method of fabrication was found to be the best. (J Prosthet Dent 2019;122:390-5)

Rapid advancements in computer-aided design and computer-aided manufacturing (CAD-CAM) have opened new pathways in the fabrication of removable partial denture (RPD) frameworks through additive and subtractive processes.[1] To produce a digital file that can be milled or 3D printed, sophisticated 3D dental modeling software programs have been used. Several commercial CAD software systems, including 3Shape Dental System and Exocad, have recently become available for 3D designing of RPD frameworks.[2]

Once digitally designed, different pathways exist for the fabrication of the RPD framework. The typical digital workflow includes obtaining a digital model of the oral hard and soft tissues. This can be accomplished directly from an intraoral digital scan or from a laboratory digital scan of a stone cast. Second, the path of insertion is defined, and undercuts are color coded based on the

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THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Trueness of removable partial denture frameworks additively manufactured with selective laser melting

Pei-Wen Peng, PhD,[a] Ching-Ying Hsu, MS,[b] Huei-Yu Huang, DDS, MS,[c] Jen-Chih Chao, MS,[d] and Wei-Fang Lee, MS[e]

ABSTRACT

Statement of problem. Although studies have reported on selective laser melting (SLM)-fabricated removable partial dentures (RPDs), research addressing the trueness of SLM-fabricated RPD metal frameworks is sparse.

Purpose. The purpose of this in vitro study was to evaluate the trueness of powdered cobalt-chromium (Co-Cr) or titanium-6 aluminum-4 vanadium (Ti-6Al-4V) alloy frameworks for RPDs fabricated by SLM.

Material and methods. A digital scan of a Kennedy class II mandible typodont was obtained to design an RPD framework by using a computer-aided design (CAD) software program (denoted as CRF). Two experimental groups of frameworks were fabricated from the CRF by using SLM in alloys of Co-Cr (SLM-Co-Cr, n=6) and in Ti-6Al-4V (SLM-Ti-6Al-4V, n=6) while a control group was fabricated by using traditional lost-wax casting following stereolithography (CA-Co-Cr, n=6). In total, 18 RPD frameworks were digitally scanned (denoted as CRF), with each scan then superimposed on the CRF and evaluated for discrepancies by using a 3D analysis software program. A nonparametric Kruskal-Wallis test was performed to determine differences in trueness among groups (α=.05).

Results. The CA-Co-Cr group showed the highest discrepancy between CEF and CRF. Statistically significant differences were found between the CA-Co-Cr and SLM-fabricated groups (*P*=.03 for Co-Cr, and *P*=.016 for Ti-6Al-4V). However, no significant difference was found between the SLM-Co-Cr and SLM-Ti-6Al-4V groups (*P*=.787).

Conclusions. SLM-fabricated RPD frameworks exhibited higher trueness than CA-Co-Cr fabricated ones, indicating the potential of selective laser melting to produce the geometric shapes required for accurate dental restorations. (J Prosthet Dent 2020;■:■-■)

As countries face aging populations, the number of patients with partial tooth loss is rapidly growing, as elderly patients often have fewer teeth, a condition accompanied by various systemic diseases.[1] Removable partial dentures (RPDs) are a popular treatment option for patients with missing teeth.[2] Although well-fitting dentures are important to oral health, RPDs in up to 75% of patients are ill-fitting, causing discomfort and even ulceration.[3-6]

Although a number of RPD materials and advanced technologies have been developed, they are frequently manufactured by using the traditional lost-wax casting (CA) technique.[7] Traditional RPD fabrication includes the duplication of a cast, determining the best path of insertion by surveying, designing RPD components, and investing and casting; a complicated procedure that requires time as well as highly trained dental laboratory technicians.[8-10] The many steps needed during the fabrication process also result in significant opportunities for error which may result in ill-fitting dentures.[11,12]

Recently computer-assisted design and computer-aided manufacturing (CAD-CAM) has been used for

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Original article

Accuracy of removable partial denture framework fabricated by casting with a 3D printed pattern and selective laser sintering

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Abstract

Purpose

The present study aimed to compare the accuracy of removable partial denture (RPD) frameworks fabricated by 3D-printed pattern casting and those fabricated by selective laser sintering (SLS).

Methods

A partially edentulous mandibular model was used for the simulation model. Scanning of the model was performed using a dental scanner. The framework was designed by using CAD software. The 3D-printed resin pattern was formed using a

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RESEARCH AND EDUCATION

Microstructure, mechanical properties, and retentive forces of cobalt-chromium removable partial denture frameworks fabricated by selective laser melting followed by heat treatment

Wei-Fang Lee, MS,[a] Jia-Chang Wang, PhD,[b] Ching-Ying Hsu, MS,[c] and Pei-Wen Peng, PhD[d]

ABSTRACT

Statement of problem. The effect of heat treatment on the microstructure and mechanical properties of cobalt-chromium (Co-Cr) removable partial denture (RPD) frameworks fabricated by selective laser melting (SLM) is not well understood.

Purpose. The purpose of this in vitro study was to evaluate the suitability of SLM-fabricated Co-Cr alloys followed by heat treatment as a framework for RPDs by determining the microstructure and mechanical properties.

Material and methods. Dumbbell specimens and RPD frameworks were fabricated by using SLM followed by heat treatment. The effects of the heat treatment on the microstructure were studied by using optical microscopy, scanning electron microscopy (SEM), and X-ray diffraction (XRD). Tensile and insertion and removal tests were performed to study the mechanical responses of selective laser melting followed by heat treatment specimens, including the ultimate tensile strength (UTS), 0.2% yield strength (0.2% YS), elongation (E), and retentive forces. Specimens fabricated by using the traditional lost-wax process were used as a control (casting) group.

Results. X-ray diffraction indicated that the γ-face-centered cubic phase dominated SLM and selective laser melting followed by heat treatment specimens. Results from optical microscopy and SEM showed microstructural changes under different fabrication and postprocessing heat treatments; it was difficult to observe the grain boundary in the SLM group, whereas submicrometer-scale grains had formed in the selective laser melting followed by heat treatment group. The selective laser melting followed by heat treatment group exhibited the highest elongation and retentive forces compared with the casting and SLM groups.

Conclusions. SLM increased the mechanical properties of Co-Cr alloys. Postprocessing heat treatment further enhanced the tensile ductility. It is suggested that SLM followed by heat treatment is an efficient strategy for fabricating RPD frameworks. (J Prosthet Dent 2020;■:■-■)

Base metal alloys, including nickel-chromium (Ni-Cr) and cobalt-chromium (Cr-Co) alloys have been used for dental prostheses as an alternative to precious metals because the sharp increase in the gold price in the 1970s.[1,2] Although Ni-Cr alloys have excellent mechanical properties, concerns about their biocompatibility[1,3] have made Co-Cr alloys the most popular framework material for removable partial dentures (RPDs).[4-6] Co-Cr alloys offer high strength and excellent wear and corrosion resistance; however, their microstructure might be altered during the manufacturing process, affecting the mechanical properties of the definitive prosthesis.[7-9]

Lost-wax casting has been the traditional process for fabricating Co-Cr RPD frameworks[10] but is a time-consuming and labor-intensive process owing to the high melting range of the alloy.[11-13] Moreover, accuracy and mechanical

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Review

Titanium removable denture based on a one-metal rehabilitation concept

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The use of a single metal for all restorations would be necessary because it protects against metal corrosion caused by the contact of different metals. For this "one-metal rehabilitation" concept, non-alloyed commercially pure (CP) titanium should be used for all restorations. Titanium frameworks have been cast and used for the long term without catastrophic failure, whereas they have been fabricated recently using computer-aided design/computer-aided manufacturing (CAD/CAM). However, the milling process for the frameworks of removable partial dentures (RPDs) is not easy because they have very complicated shapes and consist of many components. Currently, the fabrication of RPD frameworks has been challenged by one-process molding using repeated laser sintering and high-speed milling. Laser welding has also been used typically for repairing and rebuilding titanium frameworks. Although laboratory and clinical problems still remain, the one-metal rehabilitation concept using CP titanium as a bioinert metal can be recommended for all restorations.

Keywords: CP Titanium, Removable partial denture, Casting, CAD/CAM, One-metal rehabilitation

INTRODUCTION

Non-alloyed commercially pure (CP) titanium and titanium alloys have been used for implants and prosthetic appliances as a bioinert metal[1-3]. Ideally, all restorations should be made without metal, namely, with porcelain and zirconia, for aesthetic and biocompatible reasons[4,5]. However, the frameworks of removable partial dentures (RPDs) and some implant superstructures will be made, reluctantly, with metal even in the future[6,7]. To avoid the presence of various metal combinations in patients' oral cavities, the use of a single metal for all restorations would be needed to protect against metal corrosion caused by the contact of different metals. For this "one-metal rehabilitation" concept, non-alloyed CP titanium should be used for all restorations, based on the assumption that implant treatment will be carried out if a tooth is lost.

In Tsurumi University Dental Hospital, Yokohama, Japan, CP titanium has been used for not only fixed prosthetic appliances but also prosthetic removable dentures based on the patient-first philosophy —that better safety and excellent biocompatible metal should be used in patients' mouths— from approximately 25 years ago[8,9]. Although the benefits of CP titanium dentures have been proved by clinical observations, several laboratory and clinical problems have been found[6,9]. Of the laboratory problems, casting[10-15], cutting[16,17], grinding[18,19], and polishing are not easy[20], and casting apparatus for titanium is more expensive than for the conventional dental alloys. The debonding of the denture base resin from the titanium framework[21-23], deformation of the titanium clasp[24-30], discoloration of the titanium surface[31], severe wear of titanium teeth[32-36], and much plaque accumulation[37-39] are some of the clinical problems frequently observed in our clinical practice, whereas catastrophic failures have never been found[6]. Some of these laboratory and clinical problems have been resolved by basic studies and the efforts of laboratory technicians so that cast titanium frameworks for RPDs could be constantly fabricated with clinical success[40-43].

The advantages of titanium frameworks as compared to conventional dental alloys include outstanding corrosion resistance[44,45], appropriate mechanical properties[46,47], their light weight, better fitness accuracy[48], and less metal allergy due to its excellent biocompatibility[49,50]. On the contrary, the occurrence of a chemical reaction layer from the titanium casting is an inevitable disadvantage[51,52]. As an alternate method for the manufacturing of titanium frameworks, most implant superstructures, including abutments, have been fabricated using computer-aided design/computer-aided manufacturing (CAD/CAM) instead of casting[53-55]. Using CAD/CAM, titanium frameworks for RPDs have also started being fabricated by milling titanium disks and additive manufacturing from titanium powders.

This review article outlines the laboratory and clinical problems of cast titanium removable dentures and proposes their solutions. In addition, the future trends of fabrication methods for titanium frameworks using CAD/CAM are described based on the "one-metal rehabilitation" concept.

PROBLEMS OF CAST TITANIUM DENTURES

Casting apparatuses for titanium restorations and denture frameworks were developed more than 30 years ago. Since the castability and mechanical properties of titanium castings greatly depend on the

Color figures can be viewed in the online issue, which is available at J-STAGE.

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