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Design and fabrication of an immobilization system for External Beam Radiation Therapy

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Abstract

Accurate patient immobilization is crucial in radiotherapy, especially for brain cancer treatments, to protect healthy tissues from radiation damage. Traditional thermoplastic masks and immobilization devices are widely used but often cause patient discomfort and setup inaccuracies over time. The main goal of this study is to design and fabricate a personalized head immobilization device using modern 3D digital and manufacturing technologies.

In this work, a structured light scanner was used to capture the precise 3D anatomical shape of the patient's head safely. This digital data was then used to design a customized a head immobilization device with an optimized thickness of 2.5 mm. The different parts of the customized device (mask and belts) were manufactured using Fused Deposition Modeling (FDM) 3D printing technology with an Artillery Sidewinder X1 printer, utilizing both rigid Polylactic Acid (PLA) and flexible Thermoplastic Polyurethane (TPU) filaments. Simulations with multiphysics “COMSOL” simulator were also performed in order to study the printing material responses and thermal and mechanical behavior during 3D printing and radiotherapy utilization with 6 MV photons beam and at 400 MU/min dose rate over 15 min. The fabricated immobilization device was found accurate and comfortable. PLA and TPU were also found to remain stable under 3D printing and irradiation. In conclusion, the proposed immobilization device design and fabrication technique offers a precise, comfortable, and reliable solution to improve patient setup and safety in brain cancer radiotherapy.

Keywords: Radiotherapy; Brain Cancer; Immobilization device; Structured Light Scanning; 3D Printing; Multiphysics COMSOL Simulation.

Résumé

L'immobilisation précise du patient est essentielle en radiothérapie, en particulier pour les traitements des cancers cérébraux, afin de protéger les tissus sains des dommages causés par les rayonnements. Les masques thermoplastiques traditionnels et les dispositifs d'immobilisation sont largement utilisés, mais ils provoquent souvent une gêne pour le patient ainsi qu'une diminution de la précision du positionnement au fil du temps. L'objectif principal de cette étude est de concevoir et fabriquer un dispositif personnalisé d'immobilisation de la tête en utilisant des technologies modernes numériques et de fabrication 3D.

Dans ce travail, un scanner à lumière structurée a été utilisé pour capturer avec précision et en toute sécurité la forme anatomique tridimensionnelle de la tête du patient. Ces données numériques ont ensuite servi à concevoir un dispositif personnalisé d'immobilisation de la tête avec une épaisseur optimisée de 2,5 mm. Les différentes parties du dispositif personnalisé (masque et sangles) ont été fabriquées à l'aide de la technologie d'impression 3D par dépôt de filament fondu (FDM), en utilisant une imprimante Artillery Sidewinder X1 ainsi que des filaments rigides en acide polylactique (PLA) et flexibles en polyuréthane thermoplastique (TPU).

Des simulations multiphysiques ont également été réalisées à l'aide du logiciel COMSOL afin d'étudier la réponse des matériaux d'impression ainsi que leur comportement thermique et mécanique pendant le processus d'impression 3D et lors de leur utilisation en radiothérapie avec un faisceau de photons de 6 MV à un débit de dose de 400 MU/min pendant 15 min.

Le dispositif d'immobilisation fabriqué s'est révélé précis et confortable. Les matériaux PLA et TPU ont également montré une bonne stabilité pendant l'impression 3D et sous irradiation. En conclusion, la technique proposée de conception et de fabrication du dispositif d'immobilisation offre une solution précise, confortable et fiable permettant d'améliorer le positionnement du patient et la sécurité en radiothérapie des cancers cérébraux.

Mots-clés : Radiothérapie ; Cancer de l'encéphale ; Dispositif d'immobilisation ; Scanner à lumière structurée ; Impression 3D ; Simulation par COMSOL Multiphysics

ملخص

يُعد التثبيت الدقيق للمريض أمرًا بالغ الأهمية في العلاج الإشعاعي، وخاصةً في علاج سرطانات الدماغ، وذلك لحماية الأنسجة السليمة من الأضرار الناتجة عن الإشعاع. تُستخدم الأقنعة الحرارية اللدنة وأجهزة التثبيت التقليدية على نطاق واسع، إلا أنها غالبًا ما تسبب عدم راحة للمريض وتؤدي إلى انخفاض دقة التموضع مع مرور الوقت. يتمثل الهدف الرئيسي لهذه الدراسة في تصميم وتصنيع جهاز شخصي لتثبيت الرأس باستخدام التقنيات الرقمية الحديثة وتقنيات التصنيع ثلاثي الأبعاد.

في هذا العمل، تم استخدام ماسح ضوئي يعتمد على الضوء المنظم لالتقاط الشكل التشريحي ثلاثي الأبعاد لرأس المريض بدقة وبشكل آمن. ثم استُخدمت هذه البيانات الرقمية لتصميم جهاز مخصص لتثبيت الرأس بسماكة محسّنة قدرها 2.5 مم. وتم تصنيع الأجزاء المختلفة للجهاز المخصص (القناع والأشرطة) باستخدام تقنية الطباعة ثلاثية الأبعاد بالترسيب المنصهر (FDM)، وذلك باستعمال طابعة « Artillery Sidewinder X1 » مع استخدام خيوط من حمض البولي لاكتيك (PLA) الصلب والبولي يوريثان الحراري (TPU) المرن.

كما أُجريت محاكاة متعددة الفيزياء باستخدام برنامج «COMSOL» لدراسة استجابة مواد الطباعة وسلوكها الحراري والميكانيكي أثناء عملية الطباعة ثلاثية الأبعاد وأثناء استخدامها في العلاج الإشعاعي باستخدام حزمة فوتونات بطاقة 6 ميغافولت ومعدل جرعة يبلغ 400 وحدة مراقبة في الدقيقة(MU/min) لمدة 15دقيقة.

أظهرت نتائج الدراسة أن جهاز التثبيت المُصنَّع يتميز بالدقة والراحة. كما تبين أن مادتي PLAو TPUبقيتا مستقرتين أثناء الطباعة ثلاثية الأبعاد وتحت تأثير الإشعاع. وفي الختام، توفر تقنية تصميم وتصنيع جهاز التثبيت المقترحة حلاً دقيقًا ومريحًا وموثوقًا لتحسين تموضع المرضى وتعزيز السلامة في العلاج الإشعاعي لسرطان الدماغ

الكلمات المفتاحية :العلاج الإشعاعي؛ سرطان الدماغ؛ جهاز التثبيت؛ المسح بالضوء المنظَّم؛ الطباعة ثلاثية الأبعاد؛ المحاكاة متعددة الفيزياء باستخدامCOMSOL

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