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Evaluation of a Nylon 3D-Printed Wrist Splint Through Finite Element Analysis (FEA) and User-Based Assessment

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Abstract

A wrist splint is a medical assistive device designed to limit wrist movement and provide structural support during post-operative rehabilitation. This study investigates the applicability of 3D printing technology for the fabrication of a customized wrist splint. Finite element analysis (FEA) was carried out to evaluate the mechanical performance of a nylon-based 3D-printed wrist splint, while a user assessment involving ten respondents was conducted to compare the 3D-printed prototype with the commercially available alternatives. The analysis revealed that the 3D-printed nylon splint could sustain loads well above the maximum force generated by human muscles, with normal and von-Mises stresses representing only 5.25% and 7.9% of the material's ultimate tensile strength (UTS), and maximum flexural stress corresponding to merely 1.4% of its ultimate flexural strength (UFS). Based on user assessment, the 3D-printed splint outperformed commercial ones in terms of lightness, comfort, functionality, and stiffness, though it was less favorable in price and ease of use. Additionally, the findings indicate that the nylon-based 3D-printed wrist splint adequately satisfies the fundamental functional requirements of a wrist support device. Eventually, the results affirm the significant potential of 3D printing technology as a reliable and customizable manufacturing approach for wrist splint application.

Keywords: *3D printing; assessment; FEA; wrist splint*

Abstrak

Wrist splint adalah alat bantu medis yang dirancang untuk membatasi gerakan pergelangan tangan dan memberikan dukungan struktural selama rehabilitasi pascaoperasi. Studi ini menyelidiki penerapan teknologi cetak 3D untuk fabrikasi *wrist splint* yang disesuaikan. Analisis elemen hingga (FEA) dilakukan untuk mengevaluasi kinerja mekanis *wrist splint* cetak 3D berbasis nilon, sementara asesmen atau penilaian pengguna yang melibatkan sepuluh responden dilakukan untuk membandingkan prototipe cetak 3D dengan alternatif yang tersedia secara komersial. Analisis tersebut mengungkapkan bahwa *wrist splint* nilon cetak 3D dapat menahan beban jauh di atas gaya maksimum yang dihasilkan oleh otot manusia, dengan tegangan normal dan von-Mises hanya mewakili 5,25% dan 7,9% dari kekuatan tarik maksimum (UTS) material, dan tegangan lentur maksimum hanya sesuai dengan 1,4% dari kekuatan lentur maksimum (UFS). Berdasarkan penilaian pengguna, *wrist splint* hasil cetak 3D ini mengungguli produk komersial dalam hal keringanan, kenyamanan, fungsionalitas, dan kekakuan, meskipun harganya dan kemudahan penggunaannya kurang menguntungkan. Selain itu, temuan ini menunjukkan bahwa *wrist splint* hasil cetak 3D dari nilon secara memadai memenuhi persyaratan fungsional mendasar dari alat penyangga pergelangan tangan. Pada akhirnya, hasil ini menegaskan potensi signifikan teknologi cetak 3D sebagai pendekatan manufaktur yang andal dan dapat disesuaikan untuk aplikasi *wrist splint*.

Kata kunci: 3D printing; asesmen; FEA; *wrist splint*

1. Introduction

Wrist injuries are commonly attributed to a variety of activities, particularly sports or accidents such as falls and collisions [1]. These injuries can significantly disrupt an individual's daily activities and should be addressed with proper care. Typically, wrist injuries are divided into four main categories [2], including:

1) Sprains

   A frequently occurring minor wrist injury, typically resulting from trauma such as a collision or an improper fall, is commonly characterized by localized swelling in the wrist region.

2) Torn ligament

A torn ligament may result from severe sprains, where the ligament is either partially or completely overstretched. This condition commonly arises from high-impact incidents that cause sudden wrist sprains, particularly in contact sports such as rugby, basketball, and boxing [3]. Additionally, ligament injuries can occur due to rapid wrist movements in the opposite direction, leading to excessive tension and eventual tearing of the ligament [4]. This type of injury is also prevalent among electronic sports (eSports) athletes, with studies reporting that approximately 36% of eSports players experience such conditions [5-6].

3) Dislocation

This condition involves the displacement of a bone from the wrist joint, which may subsequently result in additional injuries such as ligament tears and muscle damage [7].

4) Bone fracture

The most severe type of wrist injury is a fracture, and it commonly occurs at the base of the joint, which typically results from a high-impact trauma, such as that sustained in accidents. This condition is also frequently observed in athletes involved in contact sports [3].

Treatments for wrist injuries are varied based on the severity of the condition. In more serious cases, such as fractures or ligament tears, surgical intervention is often required, with recovery periods typically lasting several weeks, depending on the extent of the injury [8]. During the healing process, immobilization of the hand is essential to promote recovery and alleviate pain [9]. In post-operative care, wrist splints are commonly employed to stabilize the hand and prevent movement. The use of such support devices plays a critical role in both the effectiveness of treatment and the duration of recovery. However, full restoration of wrist function is not always guaranteed, and additional interventions may be necessary if healing is incomplete.

Wrist splint is a supportive device designed to restrict wrist movement during post-operative recovery. Typically constructed from materials such as polyester and cotton, as well as fastening straps, and are available in a variety of designs [10]. Achieving complete rigidity often requires the splints to be tightly secured, which can compromise user comfort. Moreover, polyester lacks sufficient stiffness to ensure full immobilization of the wrist, particularly during sleep. Additionally, certain splint designs are overly complex, making them difficult to apply without assistance. In response to these challenges, additive manufacturing or 3D printing has emerged as a potential solution to improve both the functionality and usability of wrist splints.

Filament-based additive manufacturing, commonly known as fused deposition modeling (FDM) 3D printing, is widely recognized for its numerous advantages, including: (1) the capability to fabricate objects with complex geometries [11], (2) the affordability of 3D printers [12], (3) a relatively fast production process [13-14], (4) minimal material waste [15], (5) ease of material substitution [16], and (6) the elimination of traditional tooling requirements. FDM 3D printing has been extensively applied across various domains, including the medical field [17] (venam). For instance, the fabrication of foot ankle orthoses (FAO) using polylactic acid (PLA) through FDM technology has demonstrated performance comparable to that of commercial products [18-20]. These orthoses offer several key benefits, such as high strength, increased stiffness, cost-effectiveness, and lightweight characteristics. Several studies on the fabrication of wrist splints using the FDM technique have reported similar findings using PLA and Acrylonitrile Butadiene Styrene (ABS) as the base materials [21-22]. Such findings suggest similar potential for addressing other types of materials, such as nylon, which may be considered due to its lower rigidity relative to materials used in previous studies, thereby enabling the development of a more flexible design. Moreover, research exploring the use of 3D-printed objects as final, end-use products remains limited, highlighting a gap and opportunity to further support the development of medical applications. Ultimately, this study aims to contribute not only to academic knowledge but also to the development of practical, reliable medical devices by utilizing additive manufacturing technology.

2. Materials and Methods

The design of the wrist splint was developed based on the average hand dimensions of males aged 16 to 42 years [23], with the resulting size specifications illustrated in Figure 1.

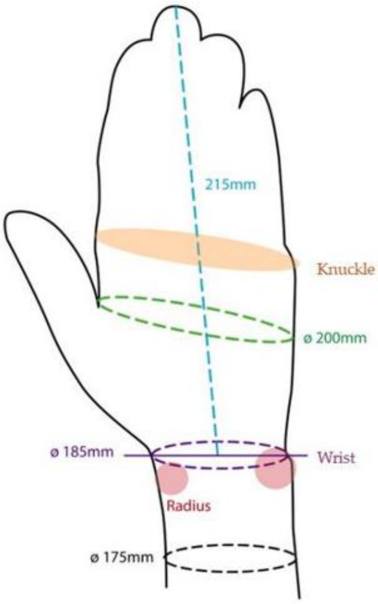


Figure 1. Anthropometric basis for wrist splint design [23]

The obtained dimensions serve as a reference for the wrist splint design, which is illustrated in Figure 2. The splint was made from nylon material and has dimensions of 185.3 mm × 190.3 mm × 3 mm.

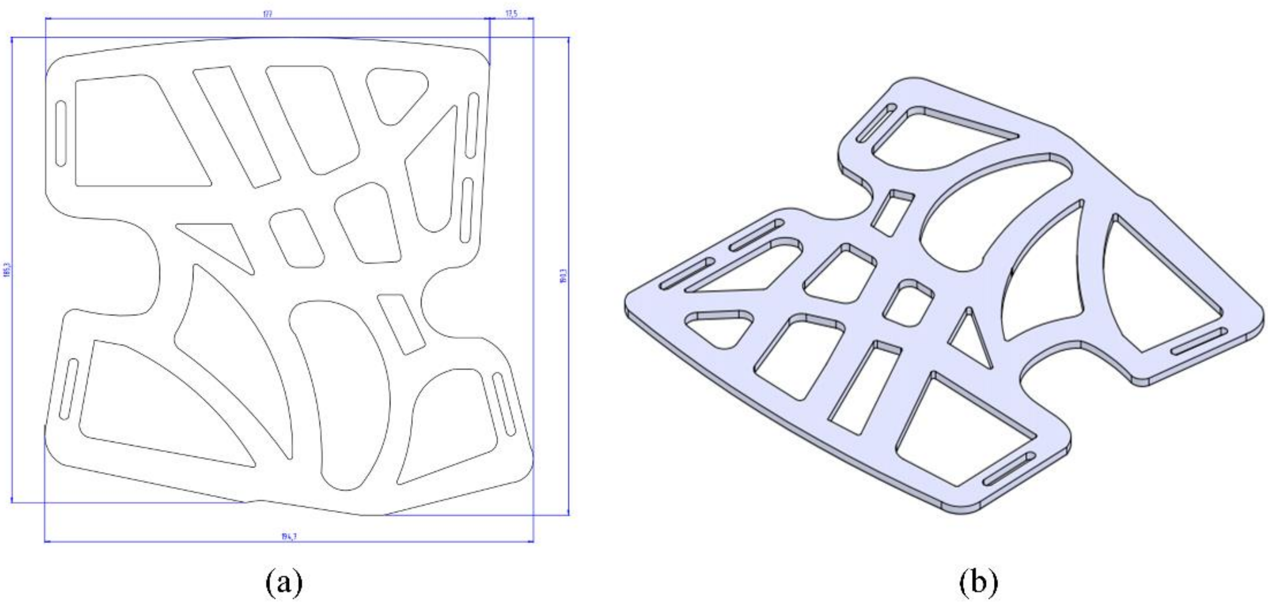


Figure 2. Design of the wrist splint: (a) 2D view, and (b) isometric view

To evaluate the performance of the nylon wrist splint, a finite element analysis was conducted using Ansys Workbench 2024 (Student Version). A load of 2.68 N/cm^2 was applied, corresponding to the maximum force generated by human muscles [24]. The finite element simulation was conducted with fixed boundary conditions and implemented using a tetrahedral meshing configuration. Then, the wrist splint was fabricated using a Creality Ender 6 3D printer, with the printing parameters listed in Table 1.

Table 1. Printing parameters of the 3D-printed wrist splint

Parameters	Units
Temperature	230 ˚C
Infill density	25%
Raster orientation	3D Enclosure
Layer thickness	0.2 mm
Printing speed	30 mm/s

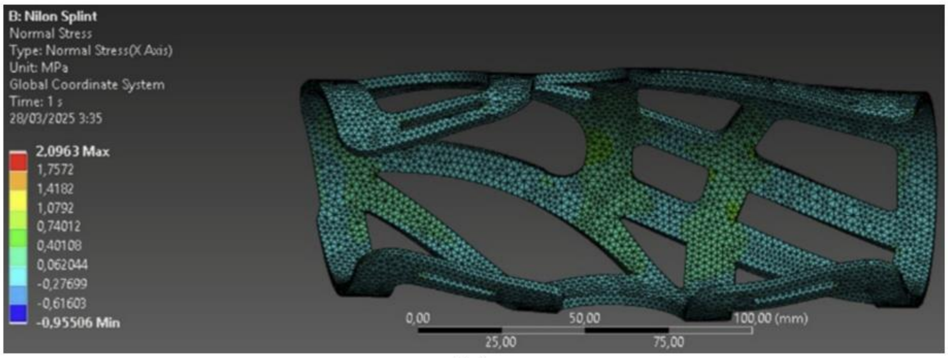
The 3D-printed wrist splint is presented in Figure 3. In order to assess the quality of the 3D-printed splint, a commercially available splint was procured (Figure 4), and comparative performance tests were carried out between the two splints. The evaluation was conducted involving ten participants, including five males and five females, whose ages ranged from 19 to 47 years. The assessments were designed to examine six parameters from the respondents’ viewpoint, including price, user comfort, weight, functional performance, rigidity, and ease of application.

Figure 3. 3D-printed wrist splint: (a) back view, and (b) top view

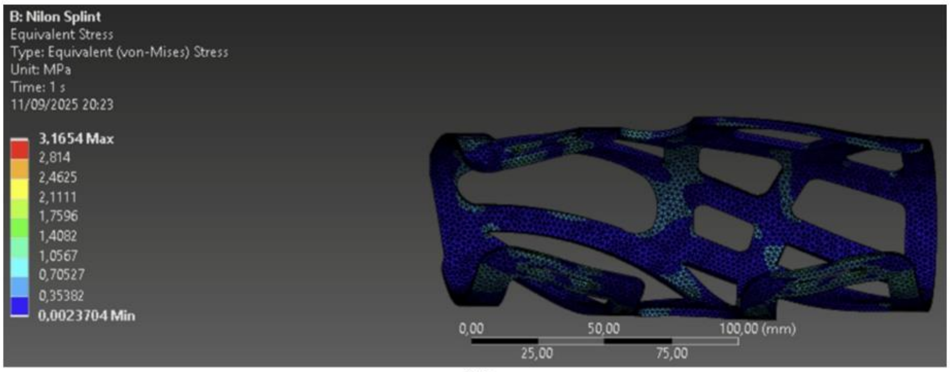
Figure 4. A commercial wrist splint for comparison: (a) back view, and (b) top view

3. Results and Discussion

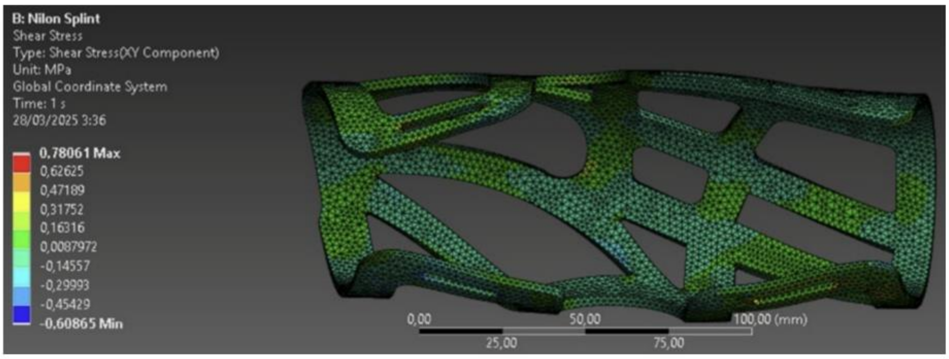
The results of the finite element analysis are shown in Figure 5. From the figure, it can be seen that the maximum values of normal stress, von Mises stress, and shear stress are 2.1 MPa, 3.16 MPa, and 0.8 MPa, respectively. Compared to previous studies, the von Mises stress generated in nylon material is lower than that of PLA and ABS, which have the maximum values of ~16 MPa and ~9 MPa, respectively [21-22]. Despite having a lower value, these findings demonstrate that the stress produced by the force exerted by human muscles is substantially below the nylon material's safety threshold. The ultimate tensile strength (UTS) of 3D-printed nylon ranged from 40 to 85 MPa [25], whereas the normal and von Mises stress values represent only 5.25% and 7.9% of the lowest UTS value, respectively. The 3D-printed nylon exhibits a maximum flexural strength (UFS) of 57 MPa [25], while the corresponding shear stress constitutes merely 1.4% of this value. Based on the three finite element stress analysis results, it can be concluded that the 3D-printed nylon exhibits a significant safety margin under the applied loading conditions.



(a)



(b)



(c)

Figure 5. The results of FEA: (a) normal stress, (b) von Mises stress, and (c) shear stress

The results of the quality assessment from ten respondents are presented in the spider chart shown in Figure 6. The assessment results indicate that the 3D-printed nylon wrist splint outperforms the commercial product in four aspects: lightness, comfort, functionality, and stiffness. The 3D-printed product demonstrates clear superiority in terms of lightness, with a mass of only 47 g compared to 178 g for the commercial product. In terms of comfort, commercial products generally incorporate metal plates to provide rigidity, as most are primarily made of fabric. However, this design reduces user comfort since the plates do not conform to the contour of the hand. Furthermore, the application of the metal plate offers unilateral wrist support, thus diminishing the overall functional effectiveness of the commercial wrist splint. In contrast to commercial wrist splints, the stiffness of the 3D-printed splints is derived entirely from its structure, without the need for additional support plates.

Despite demonstrating notable advantages, the 3D-printed wrist splint still possesses limitations when compared to commercial ones, particularly in aspects related to cost and usability. Commercial wrist splints cost IDR 75,000, while 3D-printed ones cost IDR 276,000, 3.7 times more expensive. Moreover, the simplicity of the fabric-based construction in commercial wrist splints contributes to greater user convenience when compared with the more rigid structure of 3D-printed counterparts, making it easier to use.

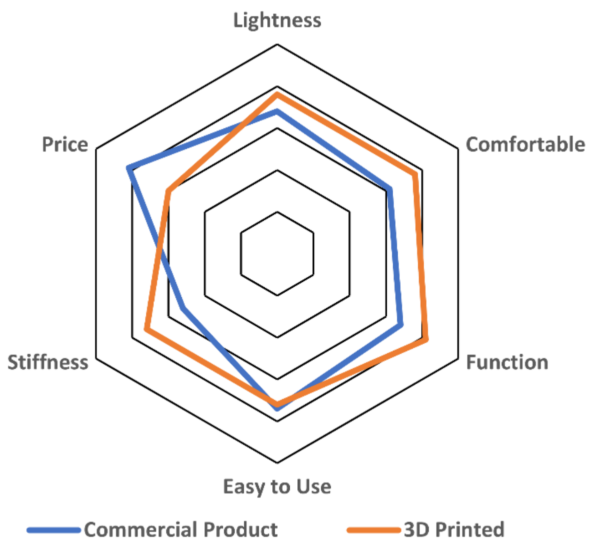


Figure 6. The results of the quality assessment between the 3D-printed and commercial wrist splints based on 6 aspects

4. Conclusion

The outcomes of this study lead to several key conclusions, which are summarized as follows:

1. According to the finite element analysis (FEA) results, the 3D-printed wrist splint fabricated from nylon demonstrates a structural strength substantially exceeding the maximum muscular load exerted by the human wrist. The maximum normal stress, von Mises stress, and shear stress values correspond to approximately 5.25%, 7.9%, and 1.4% of the UTS and UFS values, respectively.
2. The quality assessment results indicated that the 3D-printed nylon wrist splint outperformed the commercial product in four aspects: lightness, comfort, functionality, and stiffness, whereas the commercial product demonstrated superiority in terms of price and ease of use.

From the experimental findings, it can be concluded that the 3D-printed wrist splint exhibits a potential ability for a wrist support application. Furthermore, its parametric 3D design allows for customization based on individual user requirements, thereby enhancing personalization and functional suitability. Future research should investigate cost-reduction strategies that do not adversely affect functional performance, including design optimization and the exploration of alternative materials.

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