An overview of the Additive Manufacturing capabilities in the development of rehabilitation products with customized elastic properties

S de la Rosa1*, P F Mayuet1 and L Rodriguez1

1 Faculty of Engineering, Mechanical Engineering and Industrial Design Department, University of Cadiz, Av. Universidad de Cádiz 10, Puerto Real, 11519 Cádiz, Spain

*Corresponding author: sergio.delarosa@uca.es

Abstract: The advantages of AM (Additive Manufacturing) to manufacture complex geometries and custom flexible structures (shape, density, geometry etc.) provides the possibility to use the elastic properties of different materials to design elastic products with "customized" properties in order to obtain damping profiles that could be adapted to a specific energy absorbing application. One of the most widely used materials in the sense of the above is TPU (Thermoplastic Polyurethane). Several compression studies of porous TPU structures proven its effectiveness for shock absorption and have shown that the amount of energy absorbed is influenced by the density of the structure and the type of geometry used, among other parameters. This highlights the possibility of customizing the elastic behaviour of structures and could be implemented in rehabilitation programs which usually use elastic products with highly specific levels of resistance, harder or softer, to try not to strain injured muscles under dynamic loading conditions. However, a high percentage of the current research results is related to the development of support rehabilitation products under static loading conditions such as prostheses and orthotics. This paper aims to overview the current state of additive manufacturing capabilities in the development of rehabilitation products with customized elastic properties.

Keywords: Elastomers, Additive manufacturing, Rehabilitation products, TPU, Customization

1. Introduction

With the arrival of the Fourth Industrial Revolution and the current situation of globalization, the market is developing in an environment characterized by continuous innovation and the need for massive customization. This pretext has made necessary the development and use of non-traditional manufacturing methods, where AM (Additive Manufacturing) has taken an important role. This technology has been identified as a key priority for manufacturing, and is considered as one of the vital components of Industry 4.0 with the potential to transform the global manufacturing industry and European economies [1–6]. Nowadays, AM has been one of the processes with the greatest development and growth in recent years. An example of this is the increase in the use of AM after the onset of COVID19, far from the reality experienced by the industry, where the recession suffered as a result of the measures taken to contain the pandemic has been evident.

AM technologies have proven to be a very useful tool worldwide, becoming a vital technology to support better emergency medical care thanks to its inherent flexibility to produce parts on demand and its ability to customize and manufacture complex products tailored to the needs of each patient [5,7,8].
In this context, this article discusses the potential of additive manufacturing technologies with the use of elastic materials for patient rehabilitation by means of customized elastic products with personalized elastic properties.

2. AM Technologies and elastomeric materials

AM technologies consist of manufacturing through the controlled deposition of the material layer by layer, contributing exclusively where it is necessary until the final geometry is achieved. This technology can cover any stage in the life cycle of a product, and can be used from the point of view of prototyping or large-scale production of fully functional products [9].

AM processes manufacture components use 3D computer data that contains information about the object's geometry. The difference of AM technologies with respect to conventional manufacturing processes is that they allow to control more process parameters and provide a greater active interaction between material properties and process parameters [10].

This technology is very useful when low production volumes, high design complexity and frequent design changes are required, since the layer-by-layer manufacturing method allows to achieve a high level of geometric complexity with a significant reduction in time and cost of manufacturing [10,11].

The AM capabilities have made it one of the most developed technologies to date, and nowadays it shows that it can continue to effectively contribute to providing broad capacity for technology development in the future. The growing number of application areas is expected to drive industry revenue, and the market for additive manufacturing products and services is expected to almost triple between 2020 and 2028 [12].

It is observed that among the leading sectors for the use of AM, which account for more than 50% of global use, are Consumer Electronics (22%), Motor Vehicles (19%) and Medical / Dental (16%), of which a large increase is expected in the coming years [13].

Dependent on the nature of the AM technology, different types of materials are compatible such as polymers, metals, ceramics, textiles, and smart materials with elastic properties that have shape memory [14].

From this group of materials, polymers have become the center of interest for numerous applications due to the versatility and wide range of properties that they allow to obtain. In particular, elastomeric polymers are being used more and more and different lines of research are emerging according to them (Figure 1), since their ability to deform and regain their shape when a force has been applied to them is of great interest to all kinds of applications in industrial products and industrial sectors such as medical, aeronautical, naval, and automobile among many others [14–16].

![Figure 1. Evolution of the number of publications on Additive Manufacturing and their use with elastomers [17].](image-url)
There is a wide variety of elastic materials used in additive manufacturing. It is observed that most are based on TPU (Thermoplastic polyurethanes), characterized by being very versatile with properties that offer both superior performance and flexibility.

The softness of this material causes the adhesion between layers in the prints to be strong and durable [18], and its hardness can be customized, being as soft as rubber or as hard as rigid plastics [18]. This set of properties makes TPU widely used in studies of elastic properties in additive manufacturing, resulting in different studies and lines of research focused on the characterization of this material.

According to Hyojeong Lee et al [19] in the study on the shock absorption and compressibility of TPU for different filling conditions and thickness, it was determined that the compression energy increased as the filling increased. Both shock absorption and compression properties increased as thickness decreased under identical fill conditions.

Tests carried out with samples of TPU with a filling density of 10% and a thickness of 5 mm in two example applications such as the case of a crotch protector and knee protector, show that the product is suitable in terms of comfort, stability and flexibility [19], confirming that 3D printed TPU and similar materials could be used in personal protective equipment and energy absorption applications [19].

3. Customized elastic properties in the rehabilitation industry

3.1. Customized elastic properties

During the last years, several geometric structures and solid models have been proposed and investigated in order to improve their effects and behaviour from their mechanical properties and apply them to real life.

The versatility and control over the manufacturing process offered by AM technologies has made available a wide range of possibilities in manufacturing of cellular structures and geometries with more complex architectures [20–23]. This factor has led to a growing trend in the use of cellular materials and lattice structures, thanks also to the excellent energy and impact absorption properties that they may have [24–27], and which have shown promise in several applications on different industrial sectors, especially the possibility of adapting and optimizing materials for innovative lightweight and high-performance configurations [28]. At the same time, different lines of research focused on the possibility of manufacturing elastic products with "customized" properties are emerging, with the objective to obtain damping profiles that can be adapted to a specific application of energy absorption [24–27]. In addition more and more companies are applying 3D printing to consumer products and medical areas that often require materials to have flexibility, driving the growth of markets for flexible materials such as TPU (Thermoplastic Polyurethane) and silicone [29,30].

Lattice structures are topologically ordered, three-dimensional open-celled structures composed of one or more repeating unit cells, which gives them the ability to withstand the loads that are requested in the optimal directions with the consequent cost savings in manufacturing time and use of material. In addition, they are very efficient in energy, shock and vibration absorption applications, which makes them ideal for protective structures and resonance mitigation structures, and they are biocompatible thanks to their porosity, adapting well to human tissues such as bones, making them optimal for implants [31–33]. From the parametric study carried out by Simon R.G. Bates et al [27] to capture the energy absorption capacities of lattice structures and their use with elastic materials, it was shown that 3D printed lattice structures are capable of repeatedly compressing until densification without failure, being its capacity of energy absorption dependent on the deformation rate and the orientation of the cells of the structure with respect to the compression direction. In the most recent works, the specific energy absorption and the compression behaviour of extruded 2D lattices [34] and 3D lattices [22,35] have been evaluated through experimentation and finite elements, discovering that the variation of properties can effectively improve the energy absorption. In the comparison of several designs of lattice structures carried out by Fei Shen et al [36], where different geometric parameters are used, it is shown that the resistance of this type of structures varies depending on the geometric parameters used, since these
parameters can exert influence on the variation of the density and porosity of the structure, increasing or decreasing the reaction force under the same maximum deformation [25].

Making use of the capabilities of AM technologies, the fabrication of gradual density structures is possible. In the tests for the comparison of graduated density specimens versus normal specimens carried out by I. Maskery et al. [37] and H. Niknam et al. [22] among other studies, it is demonstrated that the graduated structures exhibit a different compression behaviour, being able to absorb more energy per unit volume than their non-graduated counterparts. In another study by Simon R.G. Bates et al. [38], it was observed that the increase in energy absorption efficiency for variable densities occurs only near densification (state close to the maximum state of compression) and at low compression energies. Graduated structures are able to absorb a total compression energy more than its uniform equivalent, being also more efficient at absorbing low energy compression loads and acting more efficiently for a wider range of compression energies, but its equivalent of uniform density reaches the highest maximum efficiency in its behaviour. The way in which this relationship varies according to the structure used (shape, density, geometry etc.) [38], and the variant of elastomeric material used [27], results in damping profiles that could be adapted to a specific application, offering the possibility of designing elastic products with "customized" elastic properties for each range of energies efficiently [37–41].

This pretext is gaining relevance in medical and orthopedic applications, the development of applications aimed at the development of structures that fulfill the function of blood vessels, heart valves or muscle-based structures [42–44], as well as the development of orthopedic material [45].

3.2. Future of customized and 3d printing in the rehabilitation industry

A rehabilitation strategy is a highly person-centered strategy and can be carried out through specialized and personalized programs [46,47]. In this field of study, elastic products are widely used, this is due to the incredible benefits that it offers to the body of the person in physiotherapy and rehabilitation of injuries of muscle weakness and lack of control [48].

Elastic products are used for their specificity. When a muscle is injured, other muscles build up around it to compensate for the loss, and the injured muscle may not rebuild its full strength. The elastic properties of elastic products, helps to ensure that the exact muscle is regaining its strength, rather than just the muscles that surround it. The exercises carried out with this type of product usually take advantage of the elastic behaviour to perform exercises under dynamic conditions that involve the necessary muscular effort [48–50]. Depending on the type of rehabilitation needed by the patient, different types of elastic products can be found on the market that offer different levels of resistance highly specific for their patients, so that users can start with very gentle levels so as not to strain injured muscles under dynamic load conditions [48–50]. There are types of elastic products or materials oriented towards a more or less general specific application.

In this sense, additive manufacturing provides unique advantages of flexibility and geometric freedom, and combined with acquisition technologies such as 3D scanning, allows the creation of faithful virtual and physical representations of the human anatomy [51]. From the perspective of product design, this means optimizing production, improving adaptability and integrating functionality, as well as increasing patient satisfaction. This can solve discomfort problems and provide individualized support, and most importantly, provide higher success rates [51,52].

Analysing the current literature in relation to the use of additive manufacturing in the rehabilitation sector, it is found that current medical applications are varied. Models and prototypes for diagnosis, planning, models for surgical procedures, personalized implants, regenerative medicine and rehabilitation [51,52].

From the point of view of rehabilitation, a high percentage of studies are oriented towards the development of orthoses [53] (external devices applied to the body to modify the functional or structural aspects of the neuromusculoskeletal system), and the development of methodologies for the systematic design of products for the localized treatment of different parts of the body [54–56]. For example, one of the most frequent and urgent health problems is hand rehabilitation; frequent use of laptops, strokes, etc. they have greatly increased the rate of hand injuries. There is a latent need to explore more efficient
ways to develop hand orthoses [57], as an example, the study carried out by P.S.P Orozco et al [56], shows a functional formal prototype of a static upper extremity resting orthosis for dislocation of the thumb of the hand fully customized for the user.

Other similar studies have been carried out on different parts of the patients' bodies. This is the case of the study carried out in [54], where systematic design methodologies are proposed for medical splints for the individualized treatment of a distal radius fracture, or the design and manufacture of a functional splint for partial rupture of the Achilles tendon [55]. Currently, these medical devices can be divided into two main categories: the dynamic ones that allow movement and the static ones that do not [57]. However, in most of them the rehabilitation occurs mainly under static or resting conditions where the elastic properties of elastomeric materials are not used to the maximum of their potential.

To a lesser extent, there are studies focused on the use of the characteristics offered by elastomers and cell structures. This is the case of products designed for rehabilitation processes that are developed in dynamic conditions of use by taking advantage of compression and energy absorption capacities.

It is important to highlight studies based on anatomical insoles for the foot, where lightweight internal structures are used with the aim of modifying the shock absorption properties, giving the product a greater degree of adaptation to the particular cushioning needs of each user [45,58–60].

Therefore, it is worth highlighting the great potential that the elastic properties of elastomers and lightweight cellular structures can offer for the development of elastic products with customized elastic properties for rehabilitation therapies.

4. Conclusions

This article reviewed the advances of AM (Additive Manufacturing) technologies and its use with elastic materials, paying special attention to the current state of experimental research regarding the behavior of the mechanical properties of elastic lightweight structures in compression and energy absorption applications under quasi-static and dynamics loads. The advances made in the Rehabilitation Industry were reviewed in order to analyze the possible applications for the rehabilitation of patients by means of personalized elastic products.

Additive manufacturing opens a window to innovate in the health and rehabilitation sector. In order to design and develop better tailored products, it is important to integrate rehabilitation medicine and engineering with additive manufacturing, as it allows the creation of modern and personalized products according to the needs of the patient.

The success of rehabilitation strategies focused on the user is linked to the level of personalization provided during the treatment of each patient, and therefore numerous products and devices are used that take into consideration the design of different levels of hardness or customized elastic properties for the need of each user.

These customization requirements perfectly complement the advantages offered by additive manufacturing and its versatility to manufacture complex customizable geometries (shape, density, geometry, etc.), which together with the elastic properties offered by elastomeric polymers such as TPU (Thermoplastic polyurethane), provides the possibility of designing elastic products with "personalized" properties in order to obtain cushioning profiles that could be targeted towards rehabilitation therapies with specific energy absorption profiles.

In the current literature, a high percentage of studies on the development of orthoses and products aimed at rehabilitation processes have been detected, mainly carried out under static or resting conditions, where the elastic properties of elastomeric materials are not developed to the maximum of its potential.

It is concluded that the use of the characteristics offered by elastomers and cellular structures for the development of products focused on rehabilitation sessions that are developed in dynamic conditions of use by taking advantage of compression and energy absorption capacities, is a field of potentially interesting and little studied study.
References

[1] Dilberoglu U M, Gharehpapagh B, Yaman U and Dolen M 2017 The Role of Additive Manufacturing in the Era of Industry 4.0 *Procedia Manufacturing* 11 p 545

[2] Zawadzki P and Żywicki K 2016 Smart product design and production control for effective mass customization in the industry 4.0 concept *Management and Production Engineering Review* 7 p 105

[3] Thompson M K, Moroni G, Vaneker T, Fadel G, Campbell R I, Gibson I, Bernard A, Schulz J, Graf P, Ahuja B and Martina F 2016 Design for Additive Manufacturing: Trends, opportunities, considerations, and constraints *CIRP Annals - Manufacturing Technology* 65 p 737

[4] Lettori J, Raffaeli R, Peruzzini M, Schmidt J and Pelliccieri M 2021 Additive manufacturing adoption in product design: an overview from literature and industry *Procedia Manufacturing* 51 (2) pp 655–662

[5] Rezvani Ghomi E, Khosravi F, Neisiany R E, Singh S and Ramakrishna S 2021 Future of additive manufacturing in healthcare *Current Opinion in Biomedical Engineering* 17 100255

[6] Bhuvanesh Kumar M and Sathiya P 2020 Methods and materials for additive manufacturing: A critical review on advancements and challenges *Thin-Walled Structures* 159 107228

[7] Oladapo B I, Ismail S O, Afolalu T D, Olawade D B and Zahedi M 2021 Review on 3D printing: Fight against COVID-19 *Materials Chemistry and Physics* 258 (15) 123943

[8] Tarfaoui M, Nachtane M, Goda I, Qureshi Y and Benyahia H 2020 Additive manufacturing in fighting against novel coronavirus COVID-19 *International Journal of Advanced Manufacturing Technology* 110

[9] J. L. Vallés 2014 *Additive Manufacturing in FP7 and Horizon 2020 Report from the EC Workshop on Additive Manufacturing*

[10] Abdulhameed O, Al-Ahmari A, Ameen W and Mian S H 2019 Additive manufacturing: Challenges, trends, and applications *Advances in Mechanical Engineering* 11

[11] Jiménez M, Romero L, Domínguez I A, Espinosa M D M, Domínguez M, Dom I A and Dom M 2019 Additive Manufacturing Technologies: An Overview about 3D Printing Methods and Future Prospects *Complexity* 2019 9656938

[12] Global Additive Manufacturing market 2028 (Statista)(https://www.statista.com/statistics/284863/additive-manufacturing-projected-global-market-size/) accessed on Dec 14, 2020

[13] Verhoeof L A, Budde B W, Chockalingam C, Garcia Nodar B and van Wijk A J M 2018 The effect of additive manufacturing on global energy demand: An assessment using a bottom-up approach *Energy Policy* 112 p 349

[14] León M, Marcos-Fernández A and León A M 2019 Impresión 3D con materiales elástoméricos *Revista De Plásticos Modernos* 118

[15] González-Henríquez C M, Sarabia-Vallejos M A and Rodriguez-Hernandez J 2019 Polymers for additive manufacturing and 4D-printing: Materials, methodologies, and biomedical applications *Progress in Polymer Science* 94 p 57

[16] Pazhamannil R V and Govindan P 2021 Current state and future scope of additive manufacturing technologies via vat photopolymerization *Materials Today: Proceedings* 43 (1)

[17] Science, health and medical journals, full text articles and books (Anon ScienceDirect.com) (https://www.sciencedirect.com/) accessed on May 1, 2021

[18] Harris C G, Jursik N J S, Rochefort W E and Walker T W 2019 Additive Manufacturing With Soft TPU – Adhesion Strength in Multimaterial Flexible Joints Frontiers in Mechanical Engineering 5 p 1

[19] Lee H, Eom R I and Lee Y 2019 Evaluation of the mechanical properties of porous thermoplastic polyurethane obtained by 3D printing for protective gear *Advances in Materials Science and Engineering* 2019 5838361

[20] Pham M S, Liu C, Todd I and Lerthanasarn J 2019 Damage-tolerant architected materials
inspired by crystal microstructure Nature 565 p 305

[21] Momeni K, Mofidian S M M and Bardaweel H 2019 Systematic design of high-strength multicomponent metamaterials Materials and Design 183 p 108124

[22] Niknam H and Akbarzadeh A H 2020 Graded lattice structures: Simultaneous enhancement in stiffness and energy absorption Materials and Design 196 p 109129

[23] Davami K, Mohsenizadeh M, Munther M, Palma T, Beheshti A and Momeni K 2019 Dynamic energy absorption characteristics of additively manufactured shape-recovering lattice structures Materials Research Express 6

[24] Rahman O and Koohbhor B 2020 Optimization of energy absorption performance of polymer honeycombs by density gradation Composites Part C: Open Access 3 p 100052

[25] Habib F, Iovenitti P, Masood S, Nikzad M and Ruan D 2019 Design and evaluation of 3D printed polymeric cellular materials for dynamic energy absorption International Journal of Advanced Manufacturing Technology 103 p 2347

[26] ZHU J, ZHOU H, WANG C, ZHOU L, YUAN S and ZHANG W 2021 A review of topology optimization for additive manufacturing: Status and challenges Chinese Journal of Aeronautics 34 p 91

[27] Bates S R G, Farrow I R and Trask R S 2016 3D printed polyurethane honeycombs for repeated tailored energy absorption Materials and Design 112 p 172

[28] Bhuvanesh Kumar M and Sathiya P 2020 Methods and materials for additive manufacturing: A critical review on advancements and challenges Thin-Walled Structures p 107228

[29] The Evolution of the 3D Printing Materials Market in 2019: Polymers (FacFox Docs) (https://facfox.com/docs/kb/the-evolution-of-the-3d-printing-materials-market-in-2019-polymers) accessed on Dec 22, 2020

[30] The Evolution of 3D Printing Materials Market: Trends and Opportunities in 2019 (AMFG) (https://amfg.ai/2019/11/21/the-evolution-of-3d-printing-materials-market-trends-and-opportunities-in-2019/) accessed on Feb 21, 2021

[31] Nagesha B K, Dhinakaran V, Varsha Shree M, Manoj Kumar K P, Chalawadi D and Sathish T 2020 Review on characterization and impacts of the lattice structure in additive manufacturing Materials Today 21 p 916

[32] Tao W and Leu M C 2016 Design of lattice structure for additive manufacturing International Symposium on Flexible Automation p 325

[33] ZHU J, ZHOU H, WANG C, ZHOU L, YUAN S and ZHANG W 2021 A review of topology optimization for additive manufacturing: Status and challenges Chinese Journal of Aeronautics 34 p 91

[34] Hu K, Lin K, Gu D, Yang J, Wang H and Yuan L 2019 Mechanical properties and deformation behavior under compressive loading of selective laser melting processed bio-inspired sandwich structures Materials Science and Engineering 762 p 138089

[35] Yu S, Sun J and Bai J 2019 Investigation of functionally graded TPMS structures fabricated by additive manufacturing Materials and Design 182 p 108021

[36] Shen F, Yuan S, Guo Y, Zhao B, Bai J, Qwamizadeh M, Chua C K, Wei J and Zhou K 2016 Energy Absorption of Thermoplastic Polyurethane Lattice Structures via 3D Printing: Modeling and Prediction International Journal of Applied Mechanics 8 p 1

[37] Maskery I, Hussey A, Panesar A, Aremu A, Tuck C, Ashcroft I and Hague R 2017 An investigation into reinforced and functionally graded lattice structures Journal of Cellular Plastics 53 p 151

[38] Bates S R G R G, Farrow I R R and Trask R S S 2019 Compressive behaviour of 3D printed thermoplastic polyurethane honeycombs with graded densities Materials and Design 162 p 130

[39] Habib F, Iovenitti P, Masood S, Nikzad M and Ruan D 2019 Design and evaluation of 3D printed polymeric cellular materials for dynamic energy absorption International Journal of Advanced Manufacturing Technology 103 p 2347
[40] Bates S R G, Farrow I R and Trask R S 2016 3D printed polyurethane honeycombs for repeated tailored energy absorption Materials and Design 112 p 172

[41] Schumacher C, Bickel B, Rys J, Marschner S, Daraio C and Gross M 2015 Microstructures to control elasticity in 3D printing ACM Transactions on Graphics 34 p 1

[42] Esmaeili S, Shahali M, Kordjamshidi A, Torkpoor Z, Namdari F, Samandari S S-, Ghadiri Nejad M and Khandan A 2019 An artificial blood vessel fabricated by 3D printing for pharmaceutical application Nanomedicine Journal 6 p 183

[43] Gasparotti E, Vignali E, Losi P, Scatto M, Fanni B M, Soldani G, Landini L, Positano V and Celi S 2019 A 3D printed melt-compounded antibiotic loaded thermoplastic polyurethane heart valve ring design: an integrated framework of experimental material tests and numerical simulations International Journal of Polymeric Materials and Polymeric Biomaterials 68 p 1

[44] Tsang H H, Tse K M, Chan K Y, Lu G and Lau A K T 2019 Energy absorption of muscle-inspired hierarchical structure: Experimental investigation Composite Structures 226 p 111250

[45] Davia-Aracil M, Hinojo-Pérez J J, Jimeno-Morenilla A and Mora-Mora H 2018 3D printing of functional anatomical insoles Computers in Industry 95 p 38

[46] Alves T, Carvalho H and Simões Lopes D 2020 Winning compensations: Adaptable gaming approach for upper limb rehabilitation sessions based on compensatory movements Journal of Biomedical Informatics 108 p 103501

[47] Wang Y, Tan Q, Pu F, Boone D and Zhang M 2020 A Review of the Application of Additive Manufacturing in Prosthetic and Orthotic Clinics from a Biomechanical Perspective Engineering 6 p 1258

[48] Martins W R, Carvalho R S, Silva M S, Blasczyk J C, Araújo J A, Carmo J Do, Rodacki A L F and Oliveira R J De 2014 Mechanical evaluation of elastic tubes used in physical therapy Physiotherapy Theory and Practice 30 p 218

[49] Nyberg A, Hedlund M, Kolberg A, Alm L, M B L Ö and Wadell K 2014 The accuracy of using elastic resistance bands to evaluate muscular strength

[50] Nyberg A 2016 Validity of using elastic bands to measure knee extension strength in older adults Journal of Novel Physiotherapy and Physical Rehabilitation 3 p 16

[51] Santos S, Soares B, Leite M and Jacinto J 2017 Design and development of a customised knee positioning orthosis using low cost 3D printers Virtual and Physical Prototyping 12 p 322

[52] Lunsford C, Grindle G, Salatin B and Dicianno B E 2016 Innovations With 3-Dimensional Printing in Physical Medicine and Rehabilitation: A Review of the Literature The Journal of Injury, function and rehabilitation 8

[53] Barrios-Muriel J, Romero-Sánchez F, Alonso-Sánchez F J and Salgado D R 2020 Advances in orthotic and prosthetic manufacturing: A technology review Materials 13

[54] Yan W, Ding M, Kong B, Xi X B and Zhou M 2019 Lightweight Splint Design for Individualized Treatment of Distal Radius Fracture Journal of Medical Systems 43

[55] Haro F B, Lopez-Silva J, Pedro P S, Juanes J A, Pedro A B S and D’Amato R 2018 Design and prototyping by additive manufacturing of a functional splint for rehabilitation of Achilles tendon intrasubstance rupture ACM International Conference Proceeding Series p 433

[56] Orozco P S P, Haro F B, Quintana P C, Pedro A B S, D’Amato R and Juanes J A 2019 Aesthetics in orthopedic products: Applications of the advanced manufacture (AM) to the industrial design of orthoses ACM International Conference Proceeding Series p 372

[57] Garcia-Garcia L A and Rodriguez-Salvador M 2018 Additive manufacturing knowledge incursion on orthopaedic devices: The case of hand orthoses Proceedings of the International Conference on Progress in Additive Manufacturing p 571

[58] Koteswari S and Yeole S N 2021 Development of 3D printed orthotic device for flat foot problem Materials Today: Proceedings

[59] Ma Z, Lin J, Xu X, Ma Z, Tang L, Sun C, Li D, Liu C, Zhong Y and Wang L 2019 Design and 3D printing of adjustable modulus porous structures for customized diabetic foot insoles International Journal of Lightweight Materials and Manufacture 2 p 57