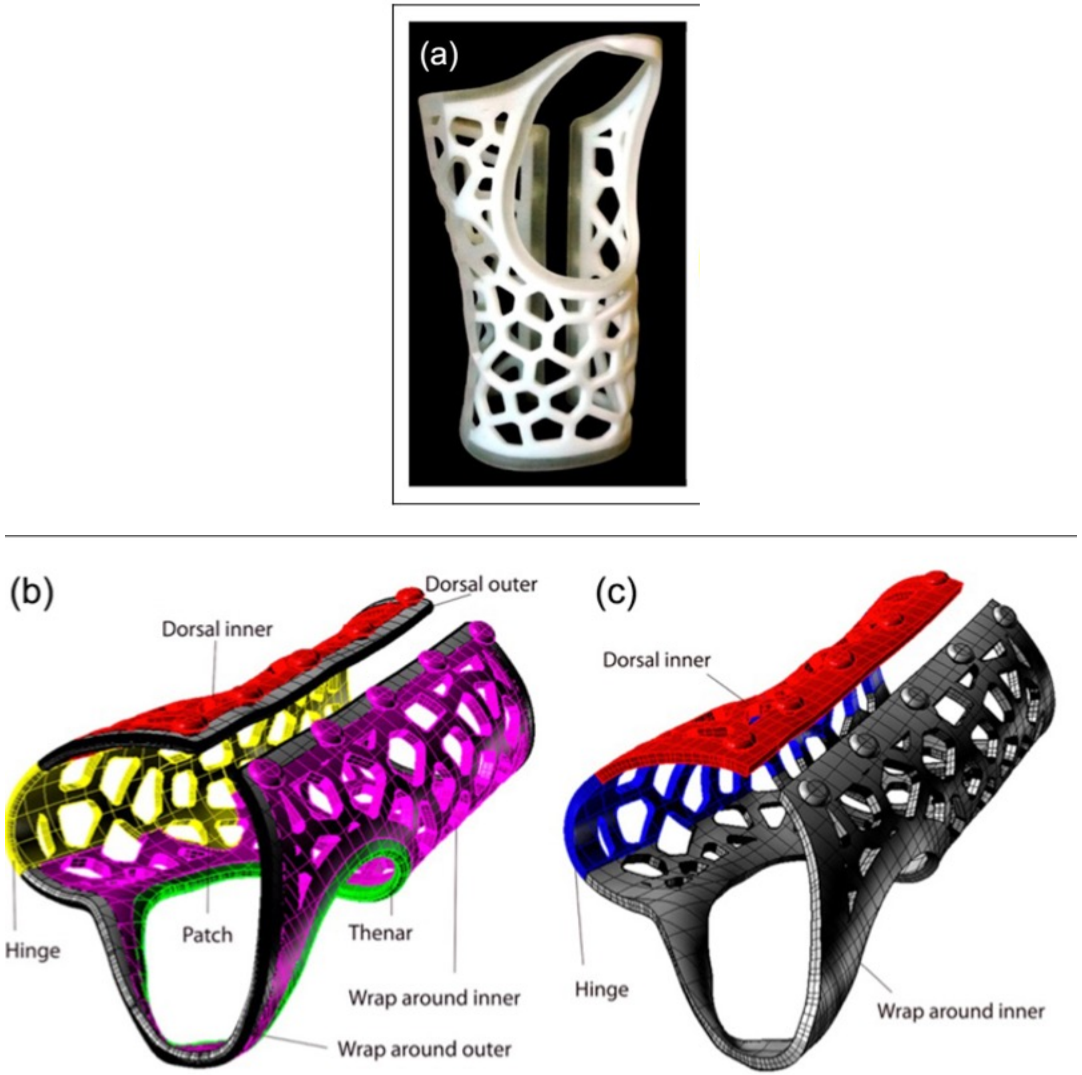
CONSIDERACIONES CLÍNICAS EN EL DISEÑO E IMPRESIÓN DE FÉRULAS EN 3D

Alejandro Ibacache P.
Doctorando en Ciencias e Ingeniería para la Salud
Universidad de Valparaíso

IMPRESIÓN DE FÉRULAS EN 3D (IF3D)

Opción viable para la fabricación de :

- Ortesis
- Férulas o abrazaderas para individuos con una variedad de condiciones ortopédicas, incluyendo fracturas, esguinces y tendinopatías.



Schwartz DA. et al 2021. https://doi.org/10.1016/j.jht.2021.10.005

LAS VENTAJAS DE LAS IF3D V/S VENDAS DE YESOS TRADICIONALES y FÉRULAS TERMOPLÁSTICAS PERSONALIZADAS

Schwartz DA. et al 2021. https://doi.org/10.1016/j.jht.2021.10.005

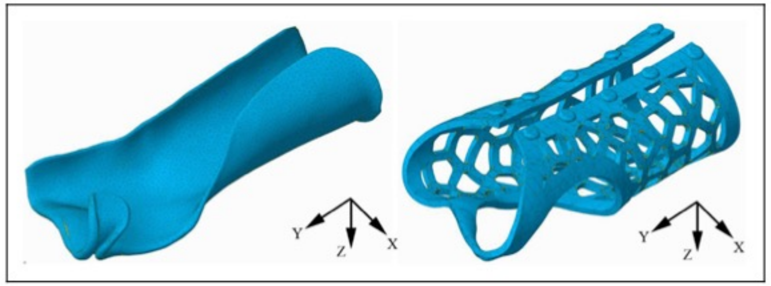
APLICACIÓN ACTUAL DE LA I3D EN EL CAMPO MÉDICO

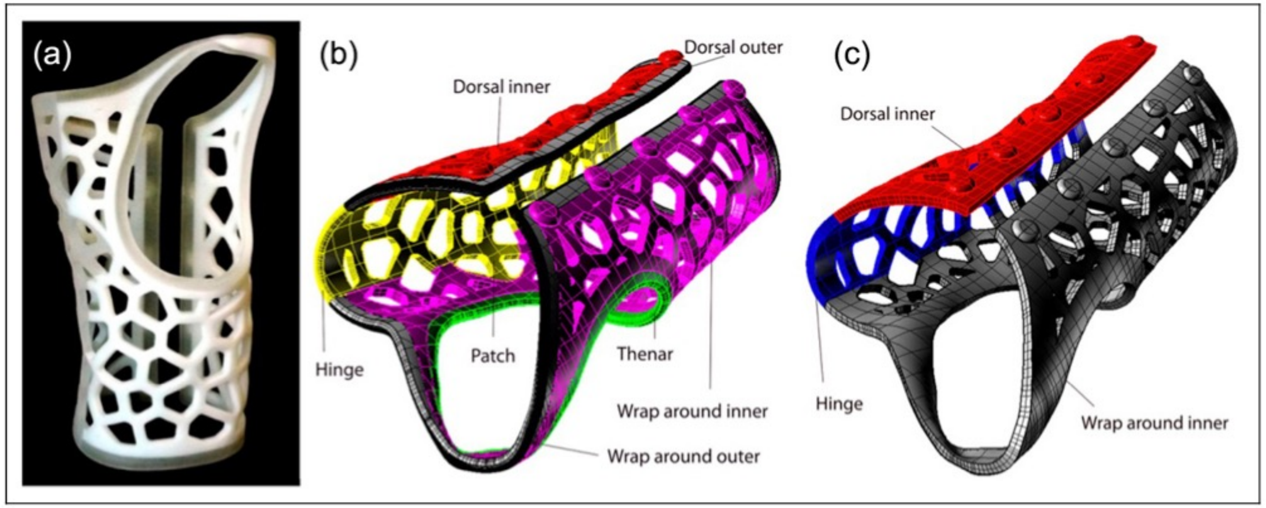
- Reconstrucción facial
- Ortodoncia
- Exoesqueletos
- Dispositivos protésicos

Schwartz DA. et al 2021. https://doi.org/10.1016/j.jht.2021.10.005

ETAPAS PARA CREAR UNA IF3D

- IF3D
- Digitalización de miembro afectado
- Modelamiento de ortesis mediante CAD
- Exportación de datos (STL)
- Impresión 3D
- Lijado, suavizado e instalación de artefacto de sujeción
- Verificación y ajustes

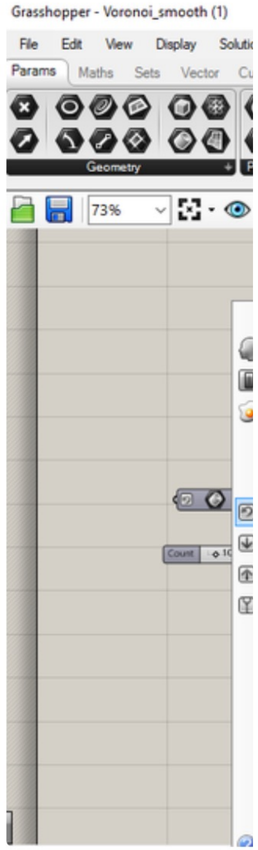


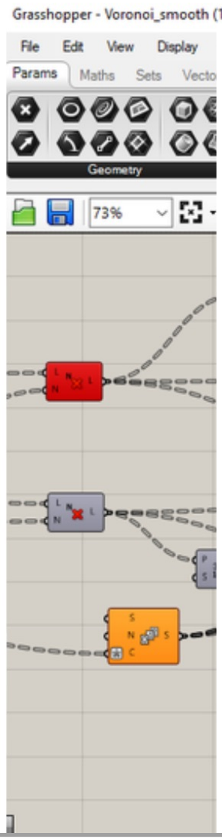


Schwartz DA. et al 2021. https://doi.org/10.1016/j.jht.2021.10.005
Cazon A. et al 2017. DOI: 10.1177/0954411917718221

How to Design Custom, 3D Printable I

By sjpiper145 in Circuits > W

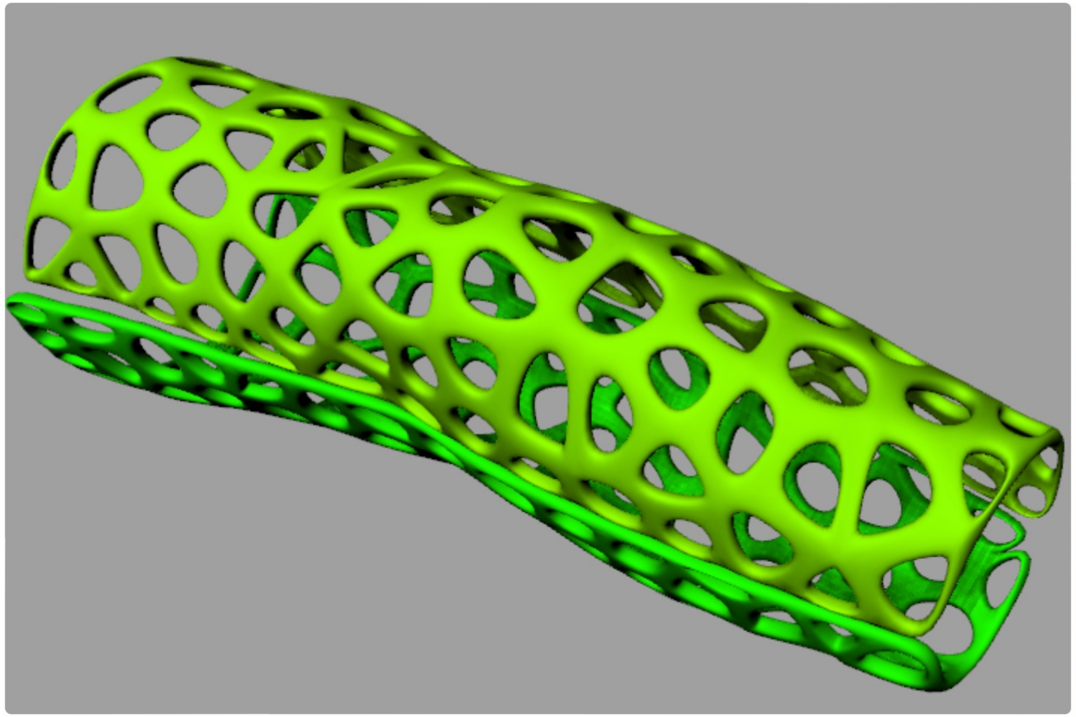




Step 6:

Step 7:

Step 8:



CONSIDERACIONES ANATÓMICAS FUNCIONALES PARA EL MODELAMIENTO DE IF3D

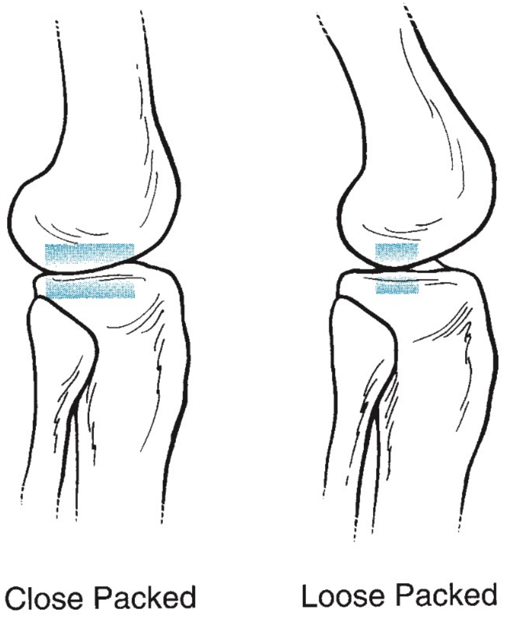
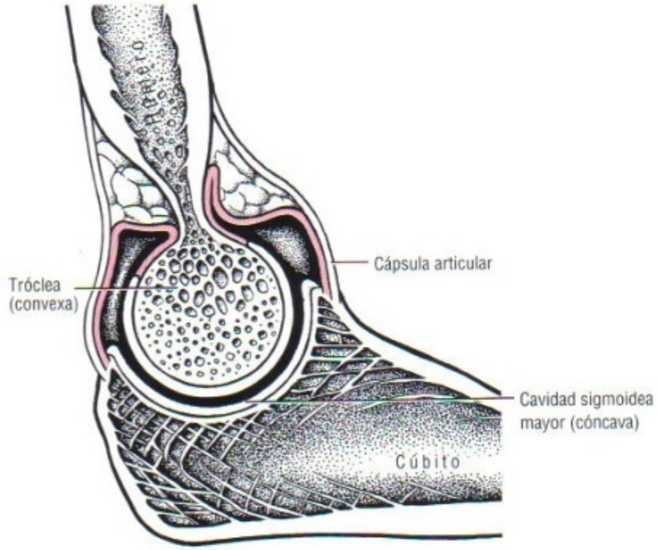


FIGURE 2-40 In the close-packed position, contact between the two joint surfaces is maximal and mobility is minimal. In the loose-packed joint position, there is less contact between the surfaces in the joint and more mobility and movement between the two surfaces.

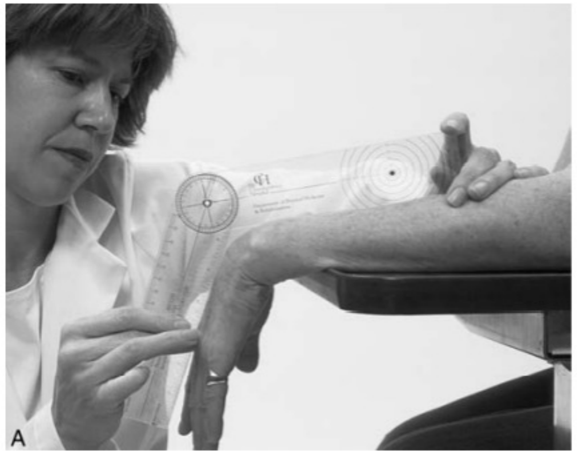


ÚNICAS POR CADA ARTICULACIÓN!

Loose Packed	Close Packed
• Mínima tensión capsula-ligamento • Movimientos accesorios favorecidos • Mínima congruencia articular (posición neutra articular)	• Máxima tensión en capsula y ligamentos • Máxima congruencia articular • Movimientos accesorios mínimos

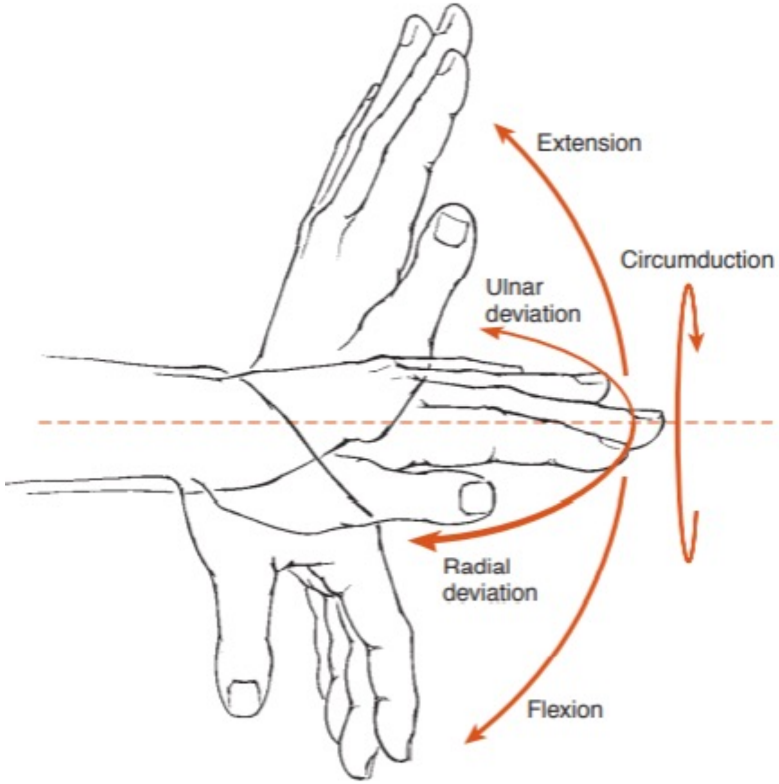
Hamill J, Knutzen K, Derrick T. Biomechanical Basis of Human Movement. Fourth Edi. Lippincott Williams & Wilkins, editor. Baltimore; 2015.
Neumman D. Kinesiology of the Muculoskeletal System, Foundation for Physical Rehabillitation. Firts Edit. Mosby. St.Louist, editor. 2002.
Oatis CA. Kinesiology: The Mechanics and Pathomechanics of Human Movement (Recall Series) 2nd Editi. 2004;946.

CONSIDERACIONES ANATÓMICAS FUNCIONALES PARA EL MODELAMIENTO DE IF3D



ARTICULACIÓN DE MUÑECA

Loose Packed	Close Packed
• Ligera extensión y desviación radial	• Extensión completa, desviación radial y ligera supinación

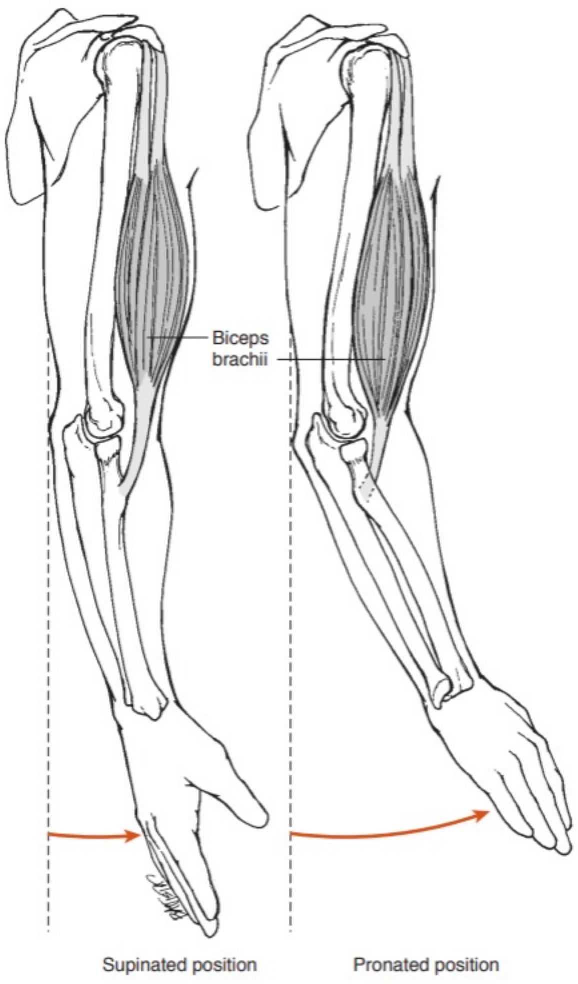


Hamill J, Knutzen K, Derrick T. Biomechanical Basis of Human Movement. Fourth Edi. Lippincott Williams & Wilkins, editor. Baltimore; 2015.
Neumman D. Kinesiology of the Muculoskeletal System, Foundation for Physical Rehabillitation. Firts Edit. Mosby. St.Louist, editor. 2002.
Oatis CA. Kinesiology: The Mechanics and Pathomechanics of Human Movement (Recall Series) 2nd Editi. 2004;946.

CONSIDERACIONES ANATÓMICAS FUNCIONALES PARA EL MODELAMIENTO DE IF3D

ARTICULACIÓN DE CODO

Loose Packed	Close Packed
• 70° de flexión y 10° de supinación	• Extensión completa y máxima supinación

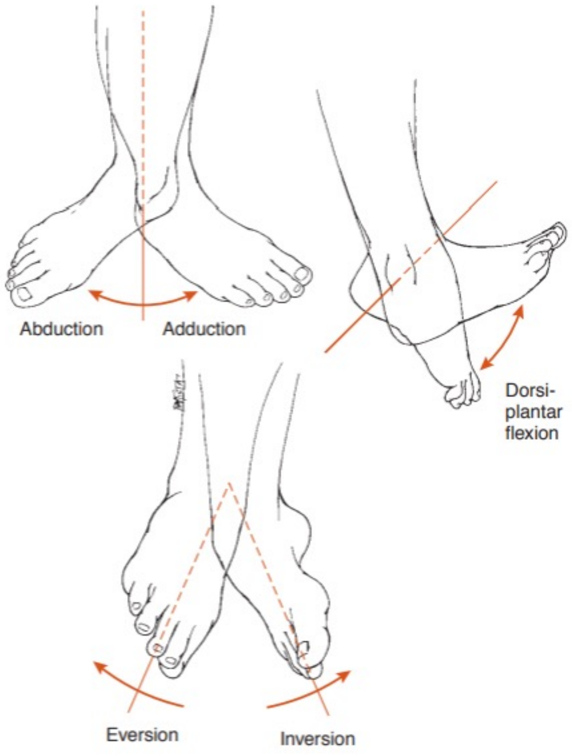


Hamill J, Knutzen K, Derrick T. Biomechanical Basis of Human Movement. Fourth Edi. Lippincott Williams & Wilkins, editor. Baltimore; 2015.
Neumman D. Kinesiology of the Muculoskeletal System, Foundation for Physical Rehabillitation. Firts Edit. Mosby. St.Louist, editor. 2002.
Oatis CA. Kinesiology: The Mechanics and Pathomechanics of Human Movement (Recall Series) 2nd Editi. 2004;946.

CONSIDERACIONES ANATÓMICAS FUNCIONALES PARA EL MODELAMIENTO DE IF3D

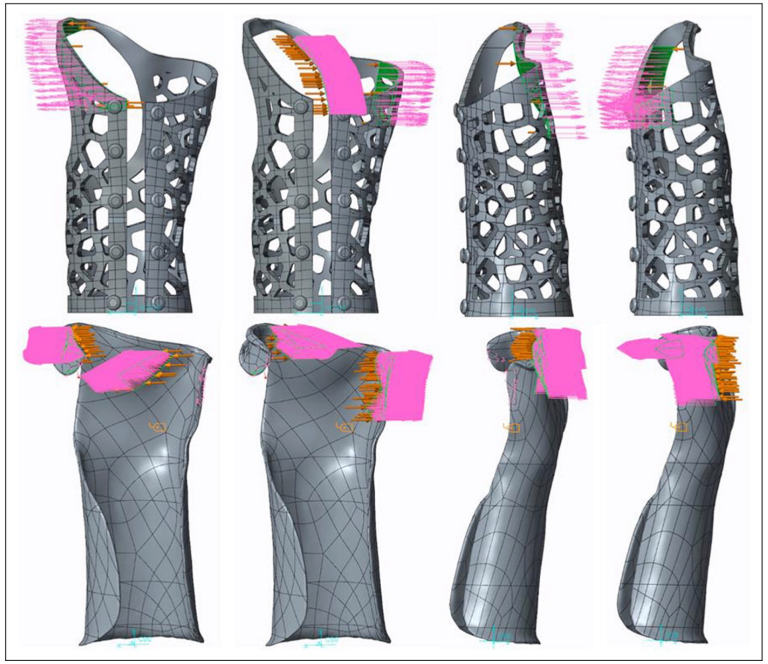
ARTICULACIÓN DE TOBILLO

Loose Packed	Close Packed
• Posición neutra (0° de flexión y 0° de extensión) y leve eversión	• Dorsiflexión máxima e inversión



Hamill J, Knutzen K, Derrick T. Biomechanical Basis of Human Movement. Fourth Edi. Lippincott Williams & Wilkins, editor. Baltimore; 2015.
Neumman D. Kinesiology of the Muculoskeletal System, Foundation for Physical Rehabillitation. Firts Edit. Mosby. St.Louist, editor. 2002.
Oatis CA. Kinesiology: The Mechanics and Pathomechanics of Human Movement (Recall Series) 2nd Editi. 2004;946.

SIMULACIÓN MECÁNICA DE LA IF3D



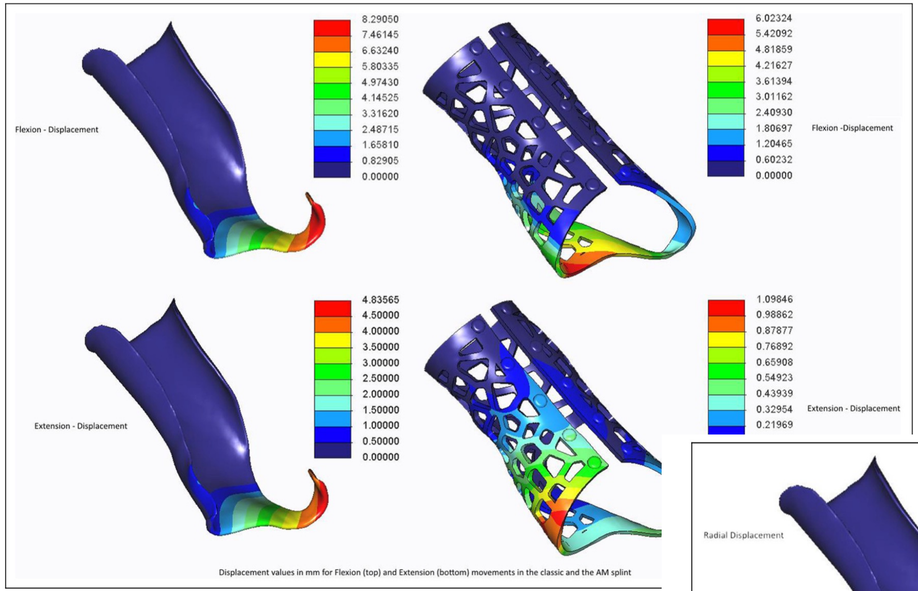


Figure 12. Displacement values (mm) for flexion (top) and extension (bottom) movements in

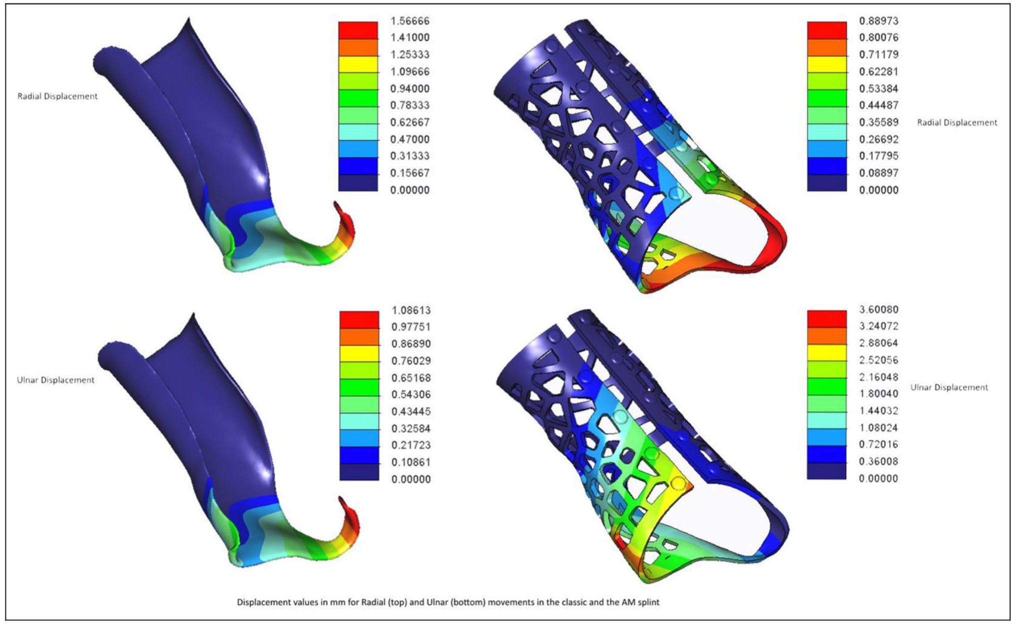


Figure 13. Displacement values (mm) for radial (top) and ulnar (bottom) movements in the classic and the AM splint.

Schwartz DA. et al 2021. https://doi.org/10.1016/j.jht.2021.10.005
Cazon A. et al 2017. DOI: 10.1177/0954411917718221

APLICACIÓN DE IF3D PATOLOGIAS DE MMSS

Table 4
Participant characteristics

Study	Number of participants	Gender	Age range	Diagnosis/clinical conditions	Follow up
Chae et al, (2020)[13]	3 (2 with upper limb conditions, 1 with back condition not included)	2 M, 1 F	55-72	Carpal tunnel syndrome ($n = 1$) Ulnar tunnel syndrome ($n = 1$)	2 weeks (CTS) 8 weeks (UTS)
Lang Chen et al, (2021)[18]	27 total 14 with upper limb fractures (13 with lower limb not included)	7 M, 7 F	21-65 Mean 47.8	Wrist fracture ($n = 7$) Elbow fracture ($n = 7$)	14-19 months Mean 13.59
Chen et al, (2017)[15]	10	4 M, 6 F	5-78	Distal radius fractures ($n = 3$), distal radius and ulnar styloid fractures ($n = 6$), distal radius and ulna fractures ($n = 1$)	2 and 6 weeks
Chen et al, (2020)[20]	60: 20 3D orthosis 20 plaster cast 20 splint	24 M, 36 F	5-78	Forearm/wrist fractures: Colles - 46 Smith's - 12 Ulnoradial diaphysis – 2	6 weeks to 3 months
Guida et al, (2019)[19]	18	17 M, 1 F	11-14 Mean 11.9	Nondisplaced metaphyseal distal radius fractures	7-15-23-30/40 days
Katt et al, (2021)[7]	2	2 M	3 years old and 6 years old	Supracondylar elbow fracture ($n = 1$) Ulnar shaft fracture ($n = 1$)	4 weeks to 12 months
Kim et al, (2018)[28]	22	2 M, 20 F	19-65 Mean 31.8 ± 7.8 control group/mean 33.8 ± 8.5 experimental group	Wrist pain/overuse	1 week
Marinho et al, (2020)[27]	6	2 M, 4 F	30-69 Mean 54.3	Thumb rhizoarthrosis	Not reported
Nam et al, (2018)[26]	3	1 M, 2 F	21-39	Hand burns	12-18 months
Oud et al, (2021)[16]	10 (1 CVA not included)	1 M, 9 F	19-79 Mean 52.1	Joint hypermobility ($n = 2$) Traumatic wrist injury ($n = 2$) STT OA ($n = 1$) Distal radius malunion ($n = 1$) RA ($n = 1$) Partial wrist fusion ($n = 1$) Charcot-Marie -Tooth disease ($n = 1$)	1 week

Schwartz DA. et al 2021. https://doi.org/10.1016/j.jht.2021.10.005

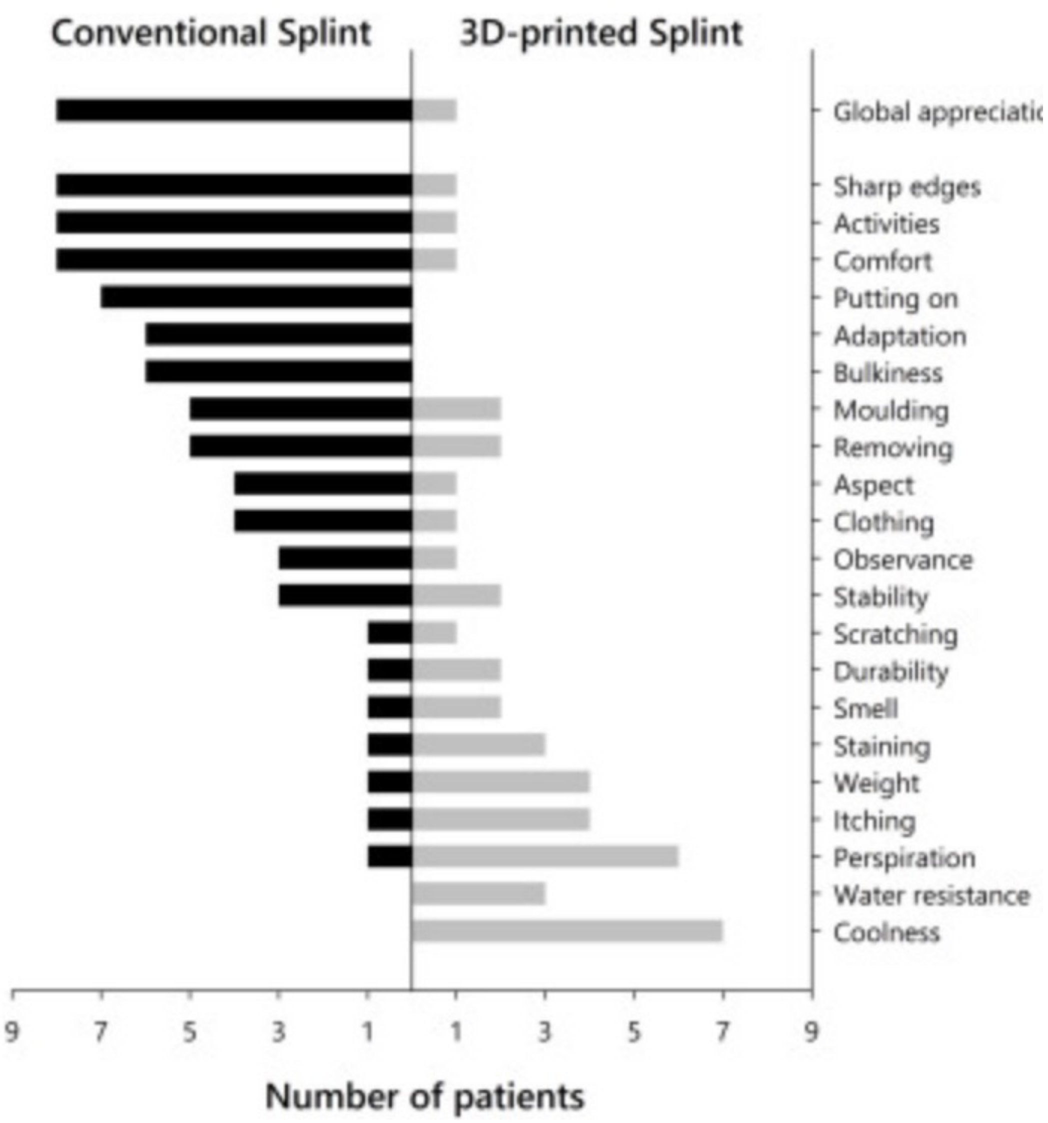
METODOLOGÍAS UTILIZADAS PARA IF3D

Table 5
3D printing materials, cost, time

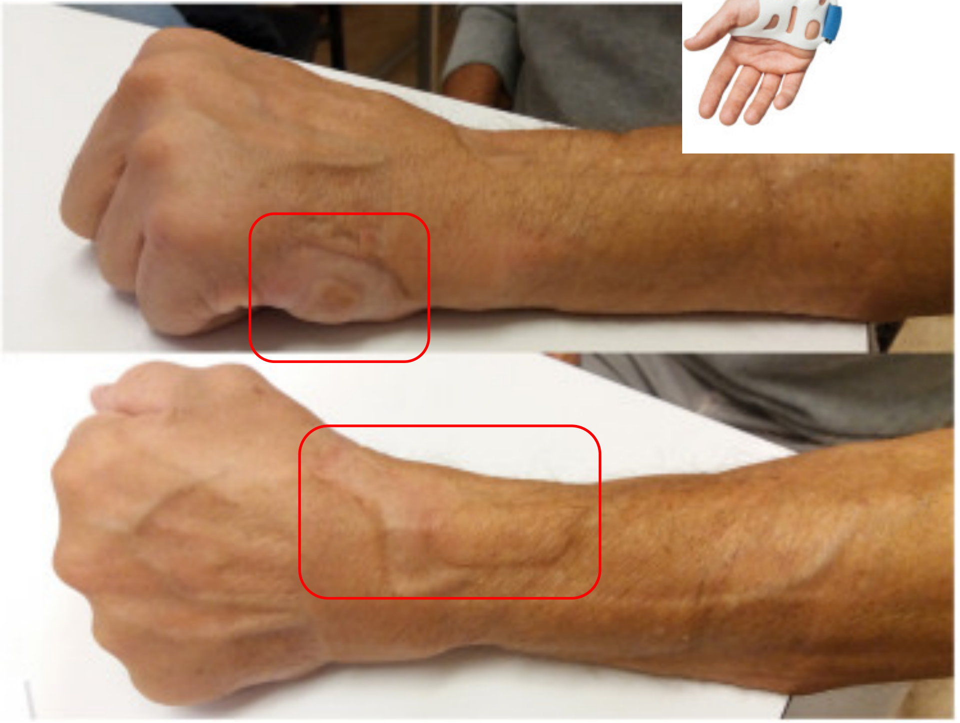
Study	Materials used	3D scanner	CAD program	3D printer
Chae et al, (2020)[13]	Thermoplastic Polyurethane Filament (TPF)	CT Scan	exported MIMICS Medical v17 (Materialize, Leuven, Belgium) Geomagic Freeform Software (#D System, Santa Clara, USA)	FINEBOT 2420 (TPC Mechatronics, Inc. Incheon, Korea)
Lang Chen et al, (2021)[18]	Biodegradable corn starch-based material Material 1/6 weight of traditional plaster and 20x as durable	Pylon-lex-Yacc (PLY) (produces VRML or WRL format file)	STL file	BiYing – 3D Instant printer, Wuhan Biotechnology Co, Ltd, Wuhan, China Curved surfaces rough – needed to print bigger image and grind surfaces smooth
Chen et al, (2017)[15]	Polyamide (PA 2200), polypropylene (PP)	CT or MRI Imaging (Aquillion CX64, Toshiba, Japan OR MR (Achieva 1.5 T, Phillips)	not reported	EOS P395 (Germany) or Stereolithography (SLA) Printer RS4500 (Union Tech, China)
Chen et al, (2020)[20]	Polyamide (PA 2200)	CT Scan (Aquillion 64, Toshiba, Japan) OR MR (Achieva 1.5 or 3.0 T Phillips, Netherlands)	Workbench 18.0 (ANSYS, USA)	SLS 3D Printer EOS P395 (Germany)
Guida et al, (2019)[19]	Thermoplastic modified ABS (Z-Ultra T, Ultra T, Olsztyn, Poland with polycarbonate and FDM	Laser scanner (3D Sense, 3D Systems Inc, Rock Hill, Soth Carolina)	Polygonal STL file – Rhionoceros version 5.0 (Robert McNeel & Associates, Seattle, WA, USA)	Not reported
Katt et al, (2021)[7]	Poly-lactic acid (PLA)	Not reported	Not reported	Not reported
Kim et al, (2018)[28]	Thermoplastic polyurethane filament (TPC)	Arctec Eva, Arctec Group	Geomagic Touch (3D Systems Corp, Rock Hills, SC, USA) and Geomagic Freeform Software (3D Systems Corp)	Fused Filament Fabrication (FFF), FINEBOT 2420 3D Printer (TPC Mechatronics Inc, Incheon, Korea)
Marinho et al. (2020)[27]	PLA	Not reported	"free software creations"	Not reported
Nam et al, (2018)[26]	FDM with TPU or PLA	Manually measured digits	Simplify 3D (Cincinnati, OH), Rhionceros 5.0 (Robert McNeel & Associates, Seattle, WA, USA), Thingiverse (MakerBot Industries, Brooklyn NY, USA)	FlashForge Creator Pro (FlashForge, City of Industry, CA, USA)
Oud et al, (2021)[16]	Nylon PA 12	White light scanner (Healthcare Partner 3D Scanner Creaform, Inc, Quebec, CA)	Rodin 4D software (Rodin 4D, Merignac, France Mesh mixer software (to adjust for pressure areas), 3. Fusion 360 Software (Autodesk, Inc.)	HP jet Fusion 4200, Hulotech Stadskanaal, The Netherlands

Schwartz DA. et al 2021. https://doi.org/10.1016/j.jht.2021.10.005

PREFERENCIAS Y COMPLICACIONES REPORTADAS



Schwartz DA. et al 2021. https://doi.org/10.1016/j.jht.2021.10.005



El Khoury G. et al 2022. https://doi.org/10.1016/j.otsr.2022.103326

INVESTIGACIONES ASOCIADAS AL USO DE IF3D EN MMSS

Table 1
Summary of evidence for 3d printed orthoses for patients with musculoskeletal conditions of the elbow, wrist, hand, and /or digits

Author/*Country*	Study design	Level of evidence	Intervention/comparison	Outcome measures	Conclusions/comments
Chae et al, (2020)[13] *Korea*	Case series	Level 4	3D printed orthoses- no comparison to conventional orthoses	JHFT, VAS, grip and pinch strength, QUEST, MMT (for ankle case)	No statistical analysis of results, CTS: improvements in VAS, JHFT scores, and grip and pinch strength UTS: improvement in VAS/ grip strength Improved QUEST scores
Chen L et al, (2021)[18] *China*	Retrospective comparative cohort	Level 3	3D printed cast compared to traditional plaster cast	X- rays to evaluate fracture healing and reduction; VAS pain scale, patient satisfaction, ROM, complications	Decreased complications ($P < .05$), less pain ($P < .05$), increased patient satisfaction ($P < .05$), increased ROM ($P < .05$) with 3D printed orthosis
Chen YJ et al, (2017)[15] *China*	Case series	Level 4	3D printed cast with no comparison	Clinical efficacy of treatment and patient satisfaction questionnaires, complications	Patient preference for 3D printed cast for comfort, less pressure sores, holds fracture reduction. 3D printing requires more time
Chen YJ et al, (2020)[20] *China*	Randomized Clinical trial	Level 2	3D printed cast compared to plaster cast and external splint	Clinical efficacy of treatment, patient satisfaction, wrist functional assessment (modified Green and O'Brien score) for pain, ROM, and grip strength	3D printed cast scores were higher for patient satisfaction ($P \leq .001$) and total score for clinical efficacy ($P = .005$). Green and O'Brien score was higher (80%) for 3D group. 3D printed cast took longer to create and was more expensive.
Guida et al, (2019)[19] *Italy*	Prospective clinical trial	Level 2	3D printed orthosis with no comparison	PRWE/ VAS pain/patient satisfaction	Significant differences ($P < .001$) for PRWE and VAS favoring 3D printed orthoses
Katt et al, (2021)[7] *USA*	Case reports	Level 4	3D printed casts with no comparison	Pilot study	Excellent clinical outcomes, no skin issues, no fracture displacement

JHFT = Jebsen Taylor Hand Function Test; ROM = range of motion; VAS = visual analog scale; QUEST = Quebec User Evaluation of Satisfaction with Assistive Technology; Complications- infections, fragment displacement, non-union; Clinical efficacy = stability of immobilization, blood circulation, pressure pain, pressure sores; OPUS = Orthotics and Prosthetics User's Survey; PRWE = Patient Rated Wrist Evaluation; SD = standard deviation; CI = Confidence Interval.
Level of Evidence-Level I = Systematic Review, Level II = Randomized Clinical Trail, Level III = Case Series/Retrospective studies, Level IV = Case Report, Level V = Expert Opinion.

Schwartz DA. et al 2021. https://doi.org/10.1016/j.jht.2021.10.005

INVESTIGACIONES ASOCIADAS AL USO DE IF3D EN MMSS

Kim, et al, (2018)[28] *South Korea*	Randomized Clinical Trial	Level 2	3D printed wrist orthosis compared to commercially available wrist cock up orthosis	PRWE/ JHFT /OPUS 1 week before and 1 week after (Short time frame of use = one week)	Pain relief in both groups/high patient satisfaction, higher OPUS score (2 items) for 3D printed orthosis. No significant differences in PRWE or JHFT between groups
Marinho et al, (2020)[27] *Brazil*	Case Series	Level 3	3D printed thumb orthosis with no comparison	QUEST, dynamometer, pinch gauge, VAS	High level satisfaction with 3D orthosis, improved strength, 5 patients out of 6 noted less pain
Nam et al, (2018)[26] *Korea*	Case Series	Level 3	3 D printed orthoses with no comparison	Modified Barthel index; ROM, patient satisfaction	Improved MBI scores (dressing, bathing domains) and improved ROM and satisfaction although actual measures were not reported
Oud et al, (2021)[16] *The Netherlands*	Prospective case series	Level 3	3D printed orthoses compared to custom orthoses (leather, silicone, polypropylene, resin or silver)	Production time and fitting time for orthoses/ patient satisfaction/ function and orthosis preference/ number of visits	Mean production time of the 3D-printed orthosis was 112 (11.0) min, compared to conventional orthosis (239 [29.2] min, 95% CI 71-182 min, $P = .001$); Mean (SD) fitting time for 3D-scanning was 5.0 (3.96) min, vs 10.3 (4.39) min for casting (95% CI 0.8-9.7 min, $P = .027$); Satisfaction scores were similar; no significant difference in number of visits

JHFT = Jebsen Taylor Hand Function Test; ROM = range of motion; VAS = visual analog scale; QUEST = Quebec User Evaluation of Satisfaction with Assistive Technology; Complications- infections, fragment displacement, non-union; Clinical efficacy = stability of immobilization, blood circulation, pressure pain, pressure sores; OPUS = Orthotics and Prosthetics User's Survey; PRWE = Patient Rated Wrist Evaluation; SD = standard deviation; CI = Confidence Interval.
Level of Evidence-Level l = Systematic Review, Level II = Randomized Clinical Trail, Level III = Case Series/Retrospective studies, Level IV = Case Report, Level V = Expert Opinion.

Schwartz DA. et al 2021. https://doi.org/10.1016/j.jht.2021.10.005