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ORIGINAL ARTICLE

Personalized weight improvement of 3D-printed testicular prostheses using polypropylene

Mejora del peso personalizada en prótesis testiculares impresas en 3D con polipropileno

*Chuanfeng Liu[1], Qian Meng[2], Weikang Wang[2], Di Chen[2], Shouxia Cao[2], Yongqiang Xia[1], and Haifang Guan[2]**

[1]Department of Urology, Linyi Maternity and Child Health Care Hospital; [2]Department of Clinical Medicine, Shandong Medical College. Shandong Province, China

Abstract

Objective: *To develop personalized 3D-printed testicular prostheses using polypropylene (PP) that closely mimic natural testicles in size, shape, and particularly weight.* **Method:** *Clinical data from two testicular resection patients were analyzed. Reference testicular density (0.99 g/mL) was derived from three specimens (mean weight: 6.67 g, volume: 6.70 mL). Target prostheses (volume: 16.75 cm³, weight: 16.58 g) were modeled through magnetic resonance imaging/computed tomography scans using SolidWorks/Mimics and printed with PP filament on a Bambu X1-Carbon printer. Comparative experiments with polylactic acid (PLA) included power analysis (Pass21 software) to determine a sample size of 14 (seven per group). Weight and density were compared using independent and single-sample t-tests, respectively.* **Results:** *Out of five printing trials, three yielded successful PP prostheses with optimized parameters, whereas two failed due to inadequate supports or material overflow. Among the two groups, PP prostheses exhibited a mean weight of 15.41 ± 1.53 g (vs. target: 16.58 g), whereas PLA prostheses were significantly heavier (19.95 ± 0.93 g, $p < 0.001$). PP density (0.98 ± 0.01 g/mL) closely matched reference testicles ($p = 0.062$), whereas PLA density (1.23 ± 0.01 g/mL) deviated significantly ($p < 0.001$).* **Conclusions:** *3D printing with PP could enable the creation of personalized testicular prostheses that meet clinical needs for size, shape, and particularly weight, potentially improving patient satisfaction.*

Keywords: *Prostheses and implants. Printing. Three-dimensional. Urologic surgical procedures. Male. Polypropylenes.*

Resumen

Objetivo: *Desarrollar prótesis testiculares 3D en polipropileno (PP) personalizadas que repliquen los testículos naturales en tamaño, forma y peso.* **Método:** *Analizamos datos de dos pacientes con resección testicular. La densidad testicular (0.99 g/ml) se calculó usando tres especímenes (peso medio: 6.67 g). Las prótesis objetivo (volumen 16.75 cm³, peso 16.58 g) se modelaron mediante RM/TC con Solidworks/Mimics y se imprimieron con PP en una Bambu X1-Carbon. Los experimentos con ácido poliláctico (PLA) incluyeron análisis de potencia (Pass21) con 14 muestras (7 por grupo). El peso y la densidad se compararon mediante pruebas t independientes y de una muestra.* **Resultados:** *Tres de cinco intentos produjeron prótesis de PP exitosas, mientras que dos fallaron por soportes inadecuados. Las prótesis de PP tuvieron un peso de 15.41 ± 1.53 g (vs. 16.58 g objetivo), significativamente menor que las de PLA (19.95 ± 0.93 g; $p < 0.001$). La densidad del PP (0.98 ± 0.01 g/ml) fue comparable a la de los testículos naturales ($p = 0.062$), mientras que las de PLA (1.23 ± 0.01 g/ml) mostraron una desviación significativa ($p < 0.001$).* **Conclusiones:** *El PP permite fabricar prótesis testiculares 3D que cumplen los requisitos clínicos de tamaño, forma y peso, mejorando potencialmente la satisfacción del paciente.*

Palabras clave: *Prótesis e implantes. Impresión tridimensional. Procedimientos quirúrgicos urológicos masculinos. Polipropileno.*

***Correspondence:**
Haifang Guan
E-mail: guanhaifang123@outlook.com

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Introduction

In clinical practice, there are numerous situations where male testicles need to be removed. The more common reasons are as follows: 1. Testicular torsion, 2. Testicular malignancy, 3. Castration treatment for prostate cancer, 4. Testicular atrophy, 5. Gender reassignment surgery, 6. Orchitis, 7. Cryptorchidism, and 8. Trauma[1-3]. Post-orchiectomy, the scrotum on the operated side becomes empty, causing not only physical pain but also significant psychological distress. The absence of a testicle has been proven to be a lifelong psychological trauma, with severe cases potentially leading to significant mental disorders[4,5].

Currently, polypropylene (PP) mesh is widely used in surgical procedures, such as abdominal wall hernia repair and gynecological surgeries, due to its excellent tissue compatibility. Clancy et al[6]. reviewed recent literature and indicated that there is no evidence linking PP mesh to systemic or autoimmune symptoms. Our team has successfully used PP mesh as a testicular prosthesis in 57 cases[7]. However, post-operative satisfaction surveys revealed that patients often desire more than just the presence of a prosthesis; they seek a natural feel and sensation, which presents a higher challenge for us. Reports indicate that patient satisfaction with testicular prosthesis implantation ranges from 71% to 100%, with the most common complaints being the prosthesis's position, size, shape, weight, and hardness[8-10]. These factors negatively impact physical exercise, sexual activity, and self-confidence, leading to dissatisfaction and regret about undergoing prosthetic surgery. Issues with prosthesis position can be resolved through surgical technique improvements. Researchers such as Park et al., Skewes et al., and Kocyigit and Narlicay[11-13] have used 3D printing technology with lattice-filled materials and customized molds to address problems with prosthesis size, shape, and hardness. However, the issue of prosthesis weight remains unresolved.

To our knowledge, no current studies have quantified and compared the weight of testicular prostheses available on the market to validate patient complaints or to provide a reference for manufacturing personalized prostheses with specific weights. Therefore, this study aims to integrate 3D printing technology to design and print testicular prosthesis models, customizing prostheses of different sizes, shapes, and weights to enhance patient satisfaction further. This has significant application value and is reported as follows.

Method

Clinical data

Clinical data were collected from two patients who underwent testicular resection at the Urology Departments of Linyi People's Hospital and Linyi Maternal and Child Health Hospital between January 2022 and December 2023.

Case 1: a 76-year-old male patient with a body mass index (BMI) of 21.78 kg/m² was admitted to the Urology Department of Linyi Maternal and Child Health Hospital. He underwent bilateral subcapsular orchiectomy as part of castration treatment for prostate cancer. Post-operative pathology indicated no cancer cell invasion in the testicles.

Case 2: a 71-year-old male patient with a BMI of 21.72 kg/m² was admitted to the Urology Department of Linyi People's Hospital. He underwent right-sided orchiectomy and spermatic cord resection due to an inguinal mass. Post-operative pathology indicated leiomyosarcoma, with no testicular invasion.

Testicle data collection

An electronic scale (model BY101, Shanghai Baiying Scales Co., Ltd.) was calibrated to zero and equipped with a windscreen. The scale was verified using a 500 g calibration weight. A measuring cup was filled with physiological saline to the 10 mL mark, ensuring the experimenter's eye level was aligned with the lowest point of the meniscus when reading the volume. The testicles were enucleated subcapsularly and immediately tied with 3-0 silk suture (model SA84G, Ethicon). The specimens were weighed immediately and then placed in the measuring cup to determine volume (with the suture suspended without tension), as shown in Fig. 1. All procedures were performed by a senior attending physician.

Data collection and 3D modeling of the target testicle

Magnetic resonance scanning or enhanced computed tomography examination was performed on the healthy testicle of the target patient. The images were exported in DICOM format and then imported into

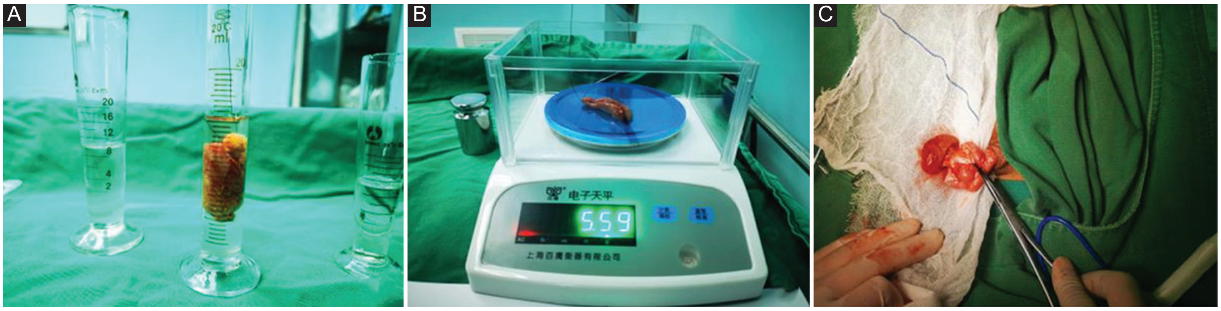

Figure 1. *Data acquisition of reference testicles.* **A:** *testicular tissue completely enucleated during surgery.* **B:** *weighing the testicle.* **C:** *measuring the testicle volume.*

Mimics software for image preprocessing. The images underwent grayscale adjustment and threshold setting, followed by threshold segmentation and edge detection to obtain the target image. Finally, the image was saved as an STL file to complete the 3D modeling.

3D printing of the target testicular prosthesis

Pre-experiment 1: after 3D modeling, the volume of the target prosthesis was measured using SolidWorks software. The weight of the target prosthesis was then calculated based on the average density. A hollow fill (center fill density) printing method was used to adjust the weight, making the target prosthesis closer to the desired weight.

Pre-experiment 2: a comparative experiment was conducted using PP and polylactic acid (PLA) materials. A single-factor analysis of two samples determined that the sample size was 14, with seven experimental subjects in each group.

Results

Numerical rounding was performed according to the national standard "Regulations on the Use of Numerals in Publications," following the rule of "rounding to the nearest even number if exactly halfway." The weighing and measurement of the prosthesis were conducted using the same electronic scale during the surgical experiment, with an accuracy of 0.01 g. An electronic caliper with an accuracy of 0.1 mm was used.

Average testicular density

Three reference testicles were obtained, with their data shown in table 1. The average weight of the testicles was 6.67 g, the average volume was 6.70 mL, and the average density was 0.99 g/mL (Table 1).

Table 1. Relevant data of the obtained testicular specimens

Testicular specimen	Weight (g)	Volume (mL)	Density (g/mL)
Testicle 1	5.29	5.50	0.96
Testicle 2	5.58	5.60	1.00
Testicle 3	9.13	9.00	1.01
Average	6.67	6.70	0.99

Acquisition of target prosthesis data

Using SolidWorks software, measurements were taken for the modeled target: length: 3.57 cm, width: 3.00 cm, height: 3.00 cm (Fig. 2). The volume was calculated as 16.75 cm³, and based on the average density, the weight of the target prosthesis was determined to be 16.58 g.

Printing of target prosthesis

Based on the weight of the target prosthesis, a hollow fill (center fill density) printing method was used to gradually adjust the weight. Considering the characteristics of the PP material and the target prosthesis, we conducted multiple printings to optimize printing parameters. We succeeded 3 times and failed 2 times, ultimately obtaining the optimal printing settings (Table 2).

The optimal support style is regular automatic support, with a support threshold angle of 55-60°. The best printing temperature is nozzle 250°C, print bed 90°C, and material softening temperature 220°C, and the room temperature is recommended to be

Table 2. 3D printing process and optimized parameter settings

Number	Printing time (min)	Prosthesis weight (g)	Support style	Fill pattern	Center fill density (%)	Result	Reason for failure
1	/	/	Branching	Straight	90	Failure	Unable to support
2	54	12.36	Branching	Straight	99	Success	/
3	/	/	Regular	Straight	100	Failure	Excessive material
4	69	15.32	Regular	Straight	99	Success	/
5	104	15.64	Regular	Concentric	100	Success	/

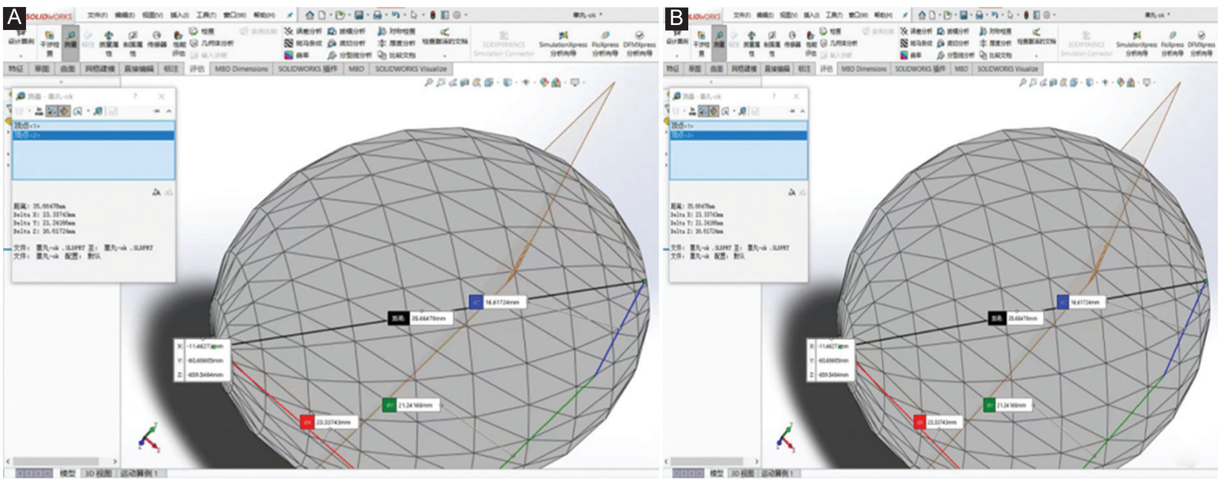

Figure 2. *Volume of the target testicular prosthesis.* **A:** *prosthesis length.* **B:** *prosthesis width.*

maintained above 15°C. The optimal initial layer printing speed is 20-25 mm/s, and the speed for subsequent layers should be < 300 mm/s. Skirt is a necessary setting, with a skirt width of 30-40 mm and 1-2 layers of skirt.

Material comparison experiment

PP and general-purpose material PLA were selected for comparative experiments. Using Pass21 software, a single-factor analysis of variance between two samples yielded $\delta = 5$, $\sigma = 2.5$, $1\text{-}\beta = 0.9$, with a sample size of 14, consisting of seven experimental subjects per group (Fig. 3). The weight comparison between each group was conducted using independent samples t-test (Table 3), and density comparison was assessed using a single-sample mean t-test (Table 4).

Discussion

Our study pioneers the use of medical-grade PP – a material widely validated in hernia repair – for 3D printing personalized testicular prostheses. The prostheses exhibited stable weight retention, achieved through optimized printing parameters. Critically, the BASF 1.75 mm PP filament maintained dimensional stability during printing, eliminating the risks of rupture inherent to silicone-based designs. By repurposing an established medical material, this approach bypasses lengthy regulatory re-evaluation, enabling rapid clinical translation.

Testicular prostheses have undergone continuous improvement over several decades. Several studies have shown high overall satisfaction (71-100%) among patients undergoing testicular prosthesis implantation, with concerns primarily focused on the prosthesis' position, size, shape, weight, and hardness[8-10]. Between 25.5 and 70% of patients reported the prosthesis being too hard[14,15], 20-39% mentioned the position being too high[10,14], 19-37% found the size inappropriate[16,17], 13-46% cited shape issues[18,19], and 10-38% noted the prosthesis being too heavy[18,19]. Notably, Coloplast's Torosa™ – the sole Food and Drug Administration-approved testicular implant for

Two-Sample T-Tests Assuming Equal Variance

Numeric Results for an Equal-Variance T-Test

δ = μ1 - μ2

Hypotheses: H0: δ = 0 vs. H1: δ ≠ 0

Target Power	Actual Power	N1	N2	N	δ	σ	Alpha
0.9	0.92907	7	7	14	5	2.5	0.05

References

Chow, S.C., Shao, J., Wang, H., and Lokhnygina, Y. 2018. Sample Size Calculations in Clinical Research, Third Edition. Taylor & Francis/CRC. Boca Raton, Florida.

Julious, S. A. 2010. Sample Sizes for Clinical Trials. Chapman & Hall/CRC. Boca Raton, FL.

Machin, D., Campbell, M., Fayers, P., and Pinol, A. 1997. Sample Size Tables for Clinical Studies, 2nd Edition. Blackwell Science. Malden, MA.

Zar, Jerrold H. 1984. Biostatistical Analysis (Second Edition). Prentice-Hall. Englewood Cliffs, New Jersey.

Report Definitions

Target Power is the desired power value (or values) entered in the procedure. Power is the probability of rejecting a false null hypothesis.

Actual Power is the power obtained in this scenario. Because N1 and N2 are discrete, this value is often (slightly) larger than the target power.

N1 and N2 are the number of items sampled from each population.

N = N1 + N2 is the total sample size.

μ1 and μ2 are the assumed population means.

δ = μ1 - μ2 is the difference between population means at which power and sample size calculations are made.

σ is the assumed population standard deviation for each of the two groups.

Alpha is the probability of rejecting a true null hypothesis.

Figure 3. *Sample size determined by a single-factor analysis of two samples.*

Table 3. Weight comparison between groups (X ± S)

Group	Weight	t	p
PP	15.411 ± 1.533	66.937	< 0.001
PLA	19.950 ± 0.931	-	-

PP: polypropylene; PLA: polylactic acid.

Table 4. Density comparison between groups

Index	PLA*	PP*
X ± S	1.23 ± 0.01	0.98 ± 0.012
t	63.904	2.291
p	< 0.001	0.062

(*) Compared with a density of 0.99 g/mL
PP: polypropylene; PLA: polylactic acid.

both adults and children in the US and the global market leader – provides elliptical shapes with standardized sizing options but lacks weight specifications[8]. Despite advancements in 3D printing technology to address these limitations, weight optimization remains critically understudied. Skewes et al.[11] utilized a public 3D database to obtain shape and size information of target testicles, combining 3D printing and lattice infill techniques to produce a testicular prosthesis with a relative density of 0.3-0.4, weighing 13.4-16.4 g, and an elastic modulus of 28 kPa. Kocyigit and Narlicay[12] employed a 3D scanner to capture size and shape data from bovine testicles, using a thermoplastic polyurethane filament and producing eight testicle models with hardness and weight differences of 10.64% and 81.25%, respectively, mainly for educational display. Park et al.[13] used liquid silicone as a material, designing molds through 3D printing for three different sizes to indirectly achieve variations in softness, hardness, and size of the final testicular prostheses.

Overall, current research on the weight of testicular prostheses remains limited. A survey including 171 testicular prosthesis recipients conducted a correlation analysis on issues associated with testicular prostheses, finding that excessive weight correlates with testicular size, while insufficient weight relates to improper positioning within the scrotum ($p < 0.05$)[9]. Based on practical analysis, prolonged use of excessively heavy prostheses can lead to scrotal sagging and deformation, creating a perception of oversized prostheses. Conversely, lightweight prostheses may cause scrotal contraction, resulting in more noticeable position elevation. We believe these physical factors likely interact with each other, highlighting weight as a significant factor influencing patient experiences. Due to challenges in obtaining target testicular prosthesis weight and material selection difficulties, the issue of improving testicular prosthesis quality remains unresolved. To address this, we surgically obtained measurements from three reference testicles, ingeniously quantifying their mass and volume to establish a constant (density) for calculating target testicular prostheses. During printing, we found that controlling the central filling density of the prosthesis can keep weight errors within 0.1 g. Precise quantitative studies of testicular prostheses can provide patients with a more natural feel, potentially reducing patient complaints.

Currently, there has been no exploration of mature materials specifically for the 3D printing of testicular prostheses. Skewes et al.[11] used lattice infill techniques to develop a new material suitable for 3D printing, but this material has not yet been approved for human implantation. In recent years, our team has used hernia repair mesh (PP mesh) for testicular prosthesis implantation into the scrotum, finding that PP mesh has good tissue compatibility and strong clinical application value as a scrotal filler, supported by clinical reports and technological achievements[7]. We believe that materials suitable for testicular prostheses must possess the following properties: (1) No chemical reactivity; (2) No inflammatory or allergic reactions; (3) Able to withstand certain tension; (4) Non-carcinogenic. These properties are exactly what hernia repair mesh possesses, with PP being the primary material used in hernia repair patches. Using PP for 3D printing of testicular prostheses is an innovative approach in the field of urology.

The Bambu 3D printer utilizes fused deposition modeling technology, which has the advantages of accurate printing and relatively low cost. In addition to default settings of the machine itself, we obtained multiple optimal printing parameters for the 1.75 mm PP filament: the most suitable support style for printing testicular prostheses is ordinary automatic support; optimal printing temperatures are nozzle 250°C, bed 90°C, with room temperature recommended above 15°C; optimal first layer printing speed is 20-25 mm/s, with other layer printing speeds < 300 mm/s; skirt is necessary with a width of 30-40 mm and 1-2 layers. The best parameters are determined by the material and properties of the finished product, providing valuable references for future research.

To our knowledge, this pilot study represents the first exploration of personalized weight prostheses. In addition, drug release devices can be placed inside the prosthesis to serve as drug carriers in future research on scrotal prostheses[20]. A limitation of this study is the relatively small number of reference testicles, which may not exclude the influence of individual testicular size heterogeneity, leading to potential bias in the obtained reference data. Future efforts should focus on obtaining more reference testicles for stronger validation. In addition, our study did not involve printing target testicular prostheses, including the tunica vaginalis containing the epididymis, vas deferens, and partial spermatic cord; future research should include cases of subcutaneous testicular excision for further study.

Conclusions

Our pilot study demonstrates that 3D-printed PP testicular prostheses could achieve personalized weight adjustments with clinically compatible density. The optimal printing parameters obtained from multiple printing experiments can provide valuable references for subsequent personalized prosthesis production. These findings highlight PP's potential to address patient dissatisfaction with existing prostheses, warranting further validation in larger cohorts.

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Conflicts of interest

The authors declare no conflicts of interest.

Ethical considerations

Protection of humans and animals. The authors declare that the procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation and with the World Medical Association and the Declaration of

Helsinki. The procedures were authorized by the Institutional Ethics Committee.

Confidentiality, informed consent, and ethical approval. The authors have followed their institution's confidentiality protocols, obtained informed consent from all patients, and secured approval from the Ethics Committee. SAGER guidelines have been followed as applicable to the nature of the study.

This study was approved by the Linyi Maternity and Child Health Care Hospital Research Ethics Committee (approval no. QTL-KYLL-2024044) on August 01, 2024.

Declaration on the use of artificial intelligence. The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

References

1. Matthew-Onabanjo AN, Honig S. Testicular prostheses: a historical and current review of the literature. Sex Med Rev. 2024;12:761-9.
2. Seranio N, Muncey W, Cox S, Glover F, Belladelli F, Del Giudice F, et al. (144) contemporary trends in testicular prosthesis placement: an analysis of U.S. Claims data. J Sex Med. 2024;21:i92.
3. Mohammed A, Yassin M, Hendry D, Walker G. Contemporary practice of testicular prosthesis insertion. Arab J Urol. 2015;13:282-6.
4. Martínez Y, Millán A, Gilabert R, Delgado L, De Agustín JC. Study of satisfaction of testicular prosthesis implantation in children. Cir Pediatr. 2012;25:20-3.
5. Skoogh J, Steineck G, Cavallin-Ståhl E, Wilderäng U, Håkansson UK, Johansson B, et al. Feelings of loss and uneasiness or shame after removal of a testicle by orchidectomy: a population-based long-term follow-up of testicular cancer survivors. Int J Androl. 2011;34:183-92.
6. Clancy C, Jordan P, Ridgway PF. Polypropylene mesh and systemic side effects in inguinal hernia repair: current evidence. Ir J Med Sci. 2019;188:1349-56.
7. An J, Liu Y, Zhang ZM, Yu CX, Xia YQ, Wang PF. Polypropylene mesh for testicular prothesis implantation: a report of 57 cases. Zhonghua Nan Ke Xue. 2015;21:816-8.
8. Hayon S, Michael J, Coward RM. The modern testicular prosthesis: patient selection and counseling, surgical technique, and outcomes. Asian J Androl. 2020;22:64-9.
9. Dieckmann KP, Anheuser P, Schmidt S, Soyka-Hundt B, Pichlmeier U, Schriefer P, et al. Testicular prostheses in patients with testicular cancer - acceptance rate and patient satisfaction. BMC Urol. 2015;15:16.
10. Srivatsav A, Balasubramanian A, Butaney M, Thirumavalavan N, McBride JA, Gondokusumo J, et al. Patient attitudes toward testicular prosthesis placement after orchiectomy. Am J Mens Health. 2019;13:1557988319861019.
11. Skewes J, Chen MY, Forrestal D, Rukin NJ, Woodruff MA. 3D printing improved testicular prostheses: using lattice infill structure to modify mechanical properties. Front Surg. 2021;8:626143.
12. Kocyigit A, Narlicay S. The production of testis biomodels using three dimensional (3D) technologies. Andrologia. 2021;53:e14171.
13. Park HJ, Kim DK, Lee BW. Development of device for patient-specific artificial testicle using 3D printing. Int J Eng Res Technol. 2019;12:2863-6.
14. Yossepowitch O, Aviv D, Wainchwaig L, Baniel J. Testicular prostheses for testis cancer survivors: patient perspectives and predictors of long-term satisfaction. J Urol. 2011;186:2249-52.
15. Araújo AS, Anacleto S, Rodrigues R, Tinoco C, Cardoso A, Oliveira C, et al. Testicular prostheses - impact on quality of life and sexual function. Asian J Androl. 2024;26:160-4.
16. Adshead J, Khoubehi B, Wood J, Rustin G. Testicular implants and patient satisfaction: a questionnaire-based study of men after orchidectomy for testicular cancer. BJU Int. 2001;88:559-62.
17. Nichols PE, Harris KT, Brant A, Manka MG, Haney N, Johnson MH, et al. Patient decision-making and predictors of genital satisfaction associated with testicular prostheses after radical orchiectomy: a questionnaire-based study of men with germ cell tumors of the testicle. Urology. 2019;124:276-81.
18. Clifford TG, Burg ML, Hu B, Loh-Doyle J, Hugen CM, Cai J, et al. Satisfaction with testicular prosthesis after radical orchiectomy. Urology. 2018;114:128-32.
19. Zilberman D, Winkler H, Kleinmann N, Raviv G, Chertin B, Ramon J, et al. Testicular prosthesis insertion following testicular loss or atrophy during early childhood--technical aspects and evaluation of patient satisfaction. J Pediatr Urol. 2007;3:461-5.
20. Chen HX, Yang S, Ning Y, Shao HH, Ma M, Tian RH, et al. Novel double-layer Silastic testicular prosthesis with controlled release of testosterone *in vitro*, and its effects on castrated rats. Asian J Androl. 2017;19:433-8.