Journal of Zhejiang University-SCIENCE B (Biomedicine & Biotechnology) in press
www.jzus.zju.edu.cn; www.springer.com/journal/11585
E-mail: jzus_b@zju.edu.cn

Correspondence

https://doi.org/10.1631/jzus.B2500391

Surficial amidogen 3D-printed poly-ether-ether-ketone implant promotes incision healing after chest wall reconstruction: a technical note

Xiao LIANG[1*], Weiwei WU[2*], Gandong ZHOU[2*], Changning SUN[3,4], Xi LIU[1], Xing LI[1], Rou HUANG[1], Yangfan HUO[1], Dequan YU[5], Zhaowei GAO[6], Dichen LI[3,4], Jiankang HE[3,4], Changquan SHI[3,4], Lijun HUANG[1✉], Xiaolong YAN[1✉], Lei WANG[1✉]

[1]*Department of Thoracic Surgery, Tangdu Hospital, the Fourth Military Medical University, Xi'an 710038, China*
[2]*School of Advanced Materials and Nanotechnology, Interdisciplinary Research Center of Smart Sensors, Xidian University, Xi'an 710126, China*
[3]*State Key Laboratory for Manufacturing Systems Engineering, Xi'an Jiaotong University, Xi'an 710049, China*
[4]*National Medical Products Administration Key Laboratory for Research and Evaluation of Additive Manufacturing Medical Devices, Xi'an Jiaotong University, Xi'an 710054, China.*
[5]*Department of Radiation Oncology, Tangdu Hospital, the Fourth Military Medical University, Xi'an 710038, China*
[6]*Department of Clinical Diagnose, Tangdu Hospital, the Fourth Military Medical University, Xi'an 710038, China*

Poly-ether-ether-ketone (PEEK) has been utilized as an implant material for over three decades (Panayotov et al., 2016). The elastic modulus of PEEK closely resembles that of human cortical bone, minimizing the occurrence of stress shielding (Oladapo et al., 2021; Wu et al., 2023). Meanwhile, the light transmittance of PEEK ensures that it does not generate metal-related artifacts in computed tomography (CT) scans, thereby facilitating the postoperative imaging evaluation of patients. Additionally, owing to its exceptional stability and remarkable resistance to environmental factors, PEEK exhibits the capability to endure preoperative physicochemical treatments while effectively preventing biochemical corrosion to implants. Therefore, PEEK implants have been subject to extensive research and achieved successful utilization in various surgical procedures(Wang et al., 2022a; Wang et al., 2022b). Importantly, PEEK is a thermoplastic polymer with a melting point of 343 °C (Cassari et al., 2023). It can be effectively utilized in additive manufacturing techniques within its optimal temperature range, such as three-dimensional printing (3DP) (Wei et al., 2023). In our previous studies (Wang, et al., 2022b; Wang et al., 2024), 3DP technology was employed to fabricate personalized PEEK implants, and over 150 implants were successfully utilized for chest wall reconstruction after wide excision.

✉ Lei WANG, tuodi1986@126.com
✉ Xiaolong YAN, yanxiaolong@fmmu.edu.cn
✉ Lijun HUANG, hljyxq@fmmu.edu.cn
*These authors contributed equally to this work
Lei WANG, https://orcid.org/0000-0003-1028-3334
Xiaolong YAN, https://orcid.org/0000-0003-2419-9707
Lijun HUANG, https://orcid.org/0009-0009-1758-0586

Received July 8, 2025; Revision accepted July 14, 2025;
Crosschecked xxx. xx, 20xx; Published online xxx. xx, 20xx

However, the soft tissue integration capacity of PEEK implants is insufficient because of their high hydrophobicity and biological inertness (Chen et al., 2022; Dondani et al., 2023; Zhang et al., 2023). In our previous work (Wang, et al., 2024), poor surgical wound healing was the most common postoperative complication, including increased incision drainage, delayed wound healing, and wound ulcers. Some patients underwent a second surgery to remove PEEK implants (Hu et al., 2019; Zhu et al., 2019). To improve the soft tissue integration ability of PEEK implants for chest wall reconstruction, a novel surface modification method was developed in our other previous study (Liu et al., 2021). (3-Aminopropyl) triethoxysilane was connected to the PEEK interface by chemical modification, significantly enhancing PEEK's hydrophilicity and protein affinity. The soft-tissue integration of PEEK implants occurred more rapidly and extensively at the amide interfaces *in vivo*. However, this method was only performed on small and regular PEEK samples, while PEEK implants used in clinical applications are more complex in shape and larger in size. It is very difficult to achieve uniform surface modification across all locations of irregular PEEK implants, particularly in the sternum. Otherwise, surface modification must be sufficiently stable under extreme conditions, such as during sterilization at high temperatures and pressures. It must be firmly attached to the PEEK implant to prevent falling off, especially in the chest wall, where breathing is constantly moving. In addition, the surface modification cannot weaken the mechanical properties of implants. Herein, the equipment was improved to achieve a consistent surface modification of irregularly large PEEK implants, and their stability was validated in extreme environments. A phase II single-arm clinical trial was initiated to evaluate the safety and efficacy of 3DP amino-modified PEEK (AMPEEK) implants in clinical practice. The results showed that 3DP AMPEEK implants are safe and reliable for chest wall reconstruction. Compared to PEEK implants, AMPEEK can improve perioperative efficacy and promote wound healing.

Design and Fabrication of 3DP PEEK Implants: The implant design should be based on chest wall defects after wide excision (Wang, et al., 2022b). Based on the CT image, a three-dimensional reconstruction of the chest wall was utilized for surgical planning and implant design. The ABAQUS software (Dassault, France) Finite element analysis (FEA) was employed to simulate the response and fracture probability of the implants under various load conditions (Ma et al., 2024; Sun et al., 2024). Fused filament fabrication (FFF) was utilized to fabricate the implant, as shown in Fig. 1.

Amination Treatment of 3DP PEEK Implants: For the surface preprocessing of PEEK implants, the PEEK implants were thoroughly cleaned before surface modification. First, the PEEK was sonicated sequentially with acetone, absolute ethanol, and deionized water to thoroughly remove surface contaminants (30 min, 40 kHz, 25 ℃). Subsequently, the implants were placed in 60℃ vacuum (1×10^{-3} Pa) to eliminate residual water (2 h). The PEEK implants were subjected to oxygen plasma etching at a pressure of 5 Pa and power of 5 W for 10 min. The specific steps of the surface modification process were as follows: after oxygen plasma etching, PEEK implants were nitrogen purged for 30 minutes and then immersed in (3-aminopropyl) triethoxysilane (APTES) (Nanjing Chengong Chemical Ltd., PR. China) ethanol solution (0.016 mol/L concentration). The reaction was protected to ensure oxygen-free state by applying nitrogen and continuous magnetic stirring (200 r/min) for 24 h (25 ℃). 5% triethylamine/ethanol solution (volume ratio) was used for quenched unreacted silica hydroxyl. The implants were ultrasonically cleaned three times by acetone, absolute ethanol, and ddH_2O. In the end, AMPEEK implants were blow-dried under nitrogen gas (0.5 MPa, 2 h) at 60 ° C in a vacuum oven. The details of methods for adjusting implant characteristics are provided in *Supplementary Methods and results.*

Characterization of Extreme Environment: In order to evaluate the physical properties and functional stability under extreme environmental conditions, AMPEEK implants were prepared and characterized after acid-base, high-temperature and high-pressure treatments. The surface morphology and composition of the samples were observed using scanning electron microscopy (SEM, SU8010, Hitachi, Japan) and energy dispersive spectrometry (EDS). Atomic Force Microscopy (AFM, Agilent 5500, Agilent Technologies Inc., USA) was employed to scan the quantitative morphological parameters of the sample surface. The surface roughness average (Ra) value was used to characterize the implants. Gwyddion 2.60 software was employed to calculate Ra values for three independent 10 μm×10 μm ranges of AFM topography images, and the final values were

reported as mean±standard deviation (SD).

Clinical Evaluation: In order to evaluate the postoperative soft tissue healing around the implants, a phase II single-arm clinical trial was initiated (clinical trial registration number: ChiCTR2300078408). Postoperative recovery indicators were recorded, including complications experienced after surgery, duration of the incision drainage tube, total volume of fluid drained from the incision, and inflammatory factors in the drainage fluid samples. The morphology of the implant and the surrounding soft tissue was observed and measured using chest CT scans at one week postoperatively. The details of methods for clinical evaluation are provided in *Supplementary methods and results.*

Statistical analysis： Descriptive data were reported as mean±SD. T-test was used to compare measurement data, and Fisher's exact test was used to compare count data. Statistical plots were generated using the GraphPad Prism statistical package. SPSS 22.0, a statistical software, was employed to analyze the statistical difference between groups (*P* value). All statistical analyses were two-tailed, with a significance level of 0.05.

The surface morphologies of PEEK, AMPEEK and AMPEEK implants in extreme environments (Ex-AMPEEK) are depicted in Fig. 1b. The surface morphology of AMPEEK remained unchanged after extreme environmental exposure. The AFM images (Fig. 1c) revealed the surface roughness of the PEEK, AMPEEK and Ex-AMPEEK implants. The Ra values of PEEK, AMPEEK and Ex-AMPEEK tablets were (0.00532±0.00672), (0.00654±0.00602), and (0.00637±0.00687) μm, respectively, with no significant differences among the groups. The elemental composition spectra (Fig. 1d) demonstrated the presence of C-N and c-Si in the C 1s XPS spectrum, N-H and N-C in the N 1s XPS spectrum for the AMPEEK and Ex-AMPEEK samples, as well as Si-O-Si, Si-OH, and Si-O-C in the Si 2p XPS spectrum. The N and Si contents showed obvious change as a result of APTES modification. No significant changes in the N and Si content on the surface of AMPEEK and Ex-AMPEEK samples could be observed (Figs. 1e and 1f). The EDS mapping results demonstrated that the uniform surface subjected to amination modification remained unaffected by extreme environmental conditions (Fig. S1). Additionally, water contact angles on PEEK ((95.35±4.73)°) were significantly greater than that of AMPEEK ((79.63±2.32)°) and Ex-AMPEEK ((78.52±1.96)°) (P<0.05, Fig. 1g), but no significant difference of water contact angles was observed between AMPEEK and Ex-AMPEEK implants. These results indicate that amination modification resulted in a uniform and hydrophilic PEEK interface, and the composition and uniformity of the surface remained unchanged despite exposure to high temperature, high pressure, acid washing, and alkali washing.

Fig. 2 illustrates the classic design process used in clinical applications. Patients with sternal tumors were scheduled to undergo wide excision and chest wall reconstruction. The presence of a chest wall tumor can be seen in Fig. 2a, while the chest CT scan reveals its precise location in the upper sternum (Fig. 2b). The resection range was meticulously planned using three-dimensional visualization techniques (Fig. 2c), and subsequent simulation indicated a chest wall defect after surgery (Fig. 2d). By referring to the normal bony structures, an implant for precise bony reconstruction was designed and prepared (Figs. 2e and 2f). FEA was employed to simulate potential implant fractures and to identify vulnerable parts and connectors that require reinforcement while weakening others accordingly (Fig. 2g). Following amino-modified surface treatment and high-temperature autoclave sterilization, AMPEEK implants were prepared for surgical application (Fig. 2h). Sixteen patients with chest wall tumors underwent wide excision of the tumor and chest wall reconstruction (Figs. 2i-2n), including seven cases of AMPEEK and nine cases of PEEK implants. The mechanical test and detailed surgery information are shown in *Supplementary Material 1* and Fig. S2.

The CT imaging performed one week after surgery allowed for the observation of implant integration with the surrounding soft tissue. Notably, patients in the PEEK group exhibited thicker low-density regions around the implants than those in the AMPEEK group, as indicated in Figs. 3a and 3b. Additionally, vacuoles were observed around the implants in the majority of patients from the PEEK group (yellow arrow in Fig. 3a). Further quantitative analyses are presented in Figs. 3c and 3d. The thickness of low-density area around implants was measured as (8.7±6.6) mm in the PEEK group and (2.0±0.8) mm in the AMPEEK group (P<0.05). Vacuoles around the implants were observed in 77.8% (7/9) of the patients in the PEEK group compared to only

14.3% (1/7) in the AMPEEK group (P<0.05). Additional postoperative CT images are shown in Fig. S3.

The average length of hospital stay was shorter in the AMPEEK group ((14.9±9.1) d) than in the PEEK group ((23.4±21.1) d), as indicated in Fig. 3e. A notable disparity regarding drainage duration was shown: (9.1±2.5) d in the AMPEEK group versus (15.7±7.6) d in the PEEK group (Fig. 3f, P<0.05). During the previous two weeks, a significantly lower volume of drainage was observed in the AMPEEK group than the PEEK group (Fig. 3g). The total amount of fluid drained from the incisions was (767.9±165.8) mL in the AMPEEK group was (1586.7±720.0) mL in the PEEK group (Fig. 3h, P<0.05). The patients who used the AMPEEK implants were able to recover and leave the hospital sooner. Patients in the AMPEEK group did not experience any perioperative or long-term complications. In contrast, those in the PEEK group encountered postoperative incision infection and long-term incision ulceration with implant infection (Fig. 3i).

Poor surgical wound healing was found to be the most common postoperative complication, including increased incision drainage, delayed wound healing, and wound ulcers. This issue has garnered the significant attention of scholars, leading to various studies on surface modification for PEEK implants (Liu et al., 2025). However, current research still lacks sufficient clinical application information regarding the surface modification of PEEK implants. Most studies are currently limited to *in vitro* or animal experiments; to date, no clinical report on the use of surface-modified PEEK implants in chest wall reconstruction has been published.

To address the above challenge, this study utilized over 150 PEEK implants in clinical practice for chest wall reconstruction. Surface modification was used as a concise and efficient approach, with straightforward modification steps and low operational difficulties. Our study is the first to apply PEEK implants with amino-modified surface for the treatment of extensive chest wall defects. The method involves plasma-etching PEEK to modify the surface, followed by the application of a silane coupling agent to covalently connect -NH_2 onto the modified PEEK surface. This combination is more stable than physical adsorption or coating and does not lose its effect by abrasion, washing, or long-term use and degradation (Ma, et al., 2024). The EDS results indicated that a uniform amino modification was achieved on the surface of AMPEEK. Clinical data also demonstrated that there was no significant disparity in clinical efficacy among patients using implants with different morphologies, and the surface amination modification did not damage the mechanical properties of PEEK. Hence, the amination modification remained stable and reproducible during the diverse geometries. To verify the stability of this surface modification method under extreme environments, we carried out a series of experiments. The results showed that the amination modification of AMPEEK was stable enough to tolerate the most extreme sterilization environment at the surgical level. The characterization data indicated that the morphology, amino-coating and hydrophilicity of AMPEEK implants remained intact after sterilization, which proves that this simplified process promotes standardization and reproducibility in clinical application, and that AMPEEK implants can withstand the preoperative sterilization treatment.

Chest wall reconstruction constitutes a complex procedure. To facilitate the standardized preparation of bony implants, we designed six distinct shapes of implant preparation patterns for various chest wall defects, including horizontal type rib, E-type rib, vertical type rib, upper segment sternum, whole sternum, and inferior segment sternum. Furthermore, a standardized manufacturing process of amination coating was proposed. These modification steps are straightforward and have low operational difficulty, and the surface amination modification does not damage the mechanical properties of PEEK. The amination modification remains stable and reproducible during the diverse geometries. This surface modification demands a single chemical reagent and a straightforward processing procedure, which are beneficial for the realization of standardized manufacturing. This simplified process not only promotes standardization and reproducibility in clinical application but can also be easily extended to large-scale production, presenting good prospects for industrial application. The application for the AMPEEK implant manufacturing certificate has now been submitted to the National Medical Products Administration of China. Once granted, the manufacturing certificate can guarantee the large-scale application of implants in the future.

In our study, the average area of chest wall defects was 228 cm^2. Perioperative observation and short-term follow-up in clinical applications did not reveal any toxic reactions associated with the AMPEEK implants.

Furthermore, patients in the AMPEEK group had a reduced length of hospital stay and fewer postoperative complications. CT images demonstrated that this straightforward surface amination modification method effectively enhances the soft tissue integration of large-sized irregular PEEK implants.

This study has several limitations. Firstly, the sample size and follow-up duration in this study was insufficient. Secondly, long-term complications such as implant breakage and displacement were not determined; such risk with AMPEEK implants should be assessed along with that of PEEK implants. In our previous study (Wang, et al., 2024), 49 patients underwent chest wall reconstruction using PEEK implants, and the median follow-up time was 36 months. Three patients developed wound infection and 2 patients had implants displacement due to tumor recurrence. No implant fracture events were observed. AMPEEK implants can promote short-term soft tissue healing, which may further reduce long-term wound adverse events. Considering that the surface modification method does not change the mechanical properties of AMPEEK implants, the long-term risk of fracture and displacement of AMPEEK implants should also be as low as that of PEEK implants.

In this work, following up from our previous research, we improved the design of the implant and preparation process and conducted a clinical application trial to evaluate the efficacy of AMPEEK implants. AMPEEK implants demonstrated definite short-term efficacy, reliable safety, early removal of the drainage tube, and shorter hospital stay. The CT images showed that the modified implants had better soft tissue integration. Our study presents a stable method for the surface amination modification of PEEK implants to yield substantial volume and intricate structure, and demonstrates the improved soft tissue integration ability and safety of AMPEEM through clinical application. Using this technology, AMPEEK implants exhibit promising potential for future applications in clinical practice.

Data availability statement

The data presented in this study are available from the corresponding author upon reasonable request.

Acknowledgments

This work was supported by the Natural Science Foundation of China (82472145), Acknowledgements Key Research and Development Program of Shaanxi Province (2024SF2-GJHX-34), Health High-level Talent Cultivation Program of Shaanxi Province, Yin Feng Plan Program of the Second Affiliated Hospital of Air Force Military Medical University (2024YFJH004)，National Development and Reform Commission Major Project Preparatory Work Projects (Western Development Preparatory Work projects）NDRC Investment [2023] No. 608.

Author contributions

Conceptualization, Wang Lei，Huang Lijun, Yan Xiaolong; Methodology, Sun Changning, Liu Xia, Li Xing, Huang Rou, Huo Yangfan, Yu Dequan, Gao Zhaowei, Li Dichen, He Jiankang, Shi Changquan; Writing-Original Draft, Liang Xiao , Wu Weiwei，Zhou Gandong; Writing-Review & Editing, all authors. All authors read and approved the final manuscript and, therefore, had full access to all the data in the study and take responsibility for the integrity and security of the data.

Compliance with ethics guidelines

Xiao LIANG, Weiwei WU, Gandong ZHOU, Changning SUN, Xi LIU, Xing LI, Rou HUANG, Yangfan HUO, Dequan YU, Zhaowei GAO, Dichen LI, Jiankang HE, Changquan SHI, Lijun HUANG, Xiaolong YAN and Lei WANG declare that they have no conflicts of interest and consent to publish.

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. Informed consent was obtained from all patients for being included in the study. This study was approved by the Medical Technology Ethics Group of Tangdu Hospital University (IRB number: TDLL-201710-09).

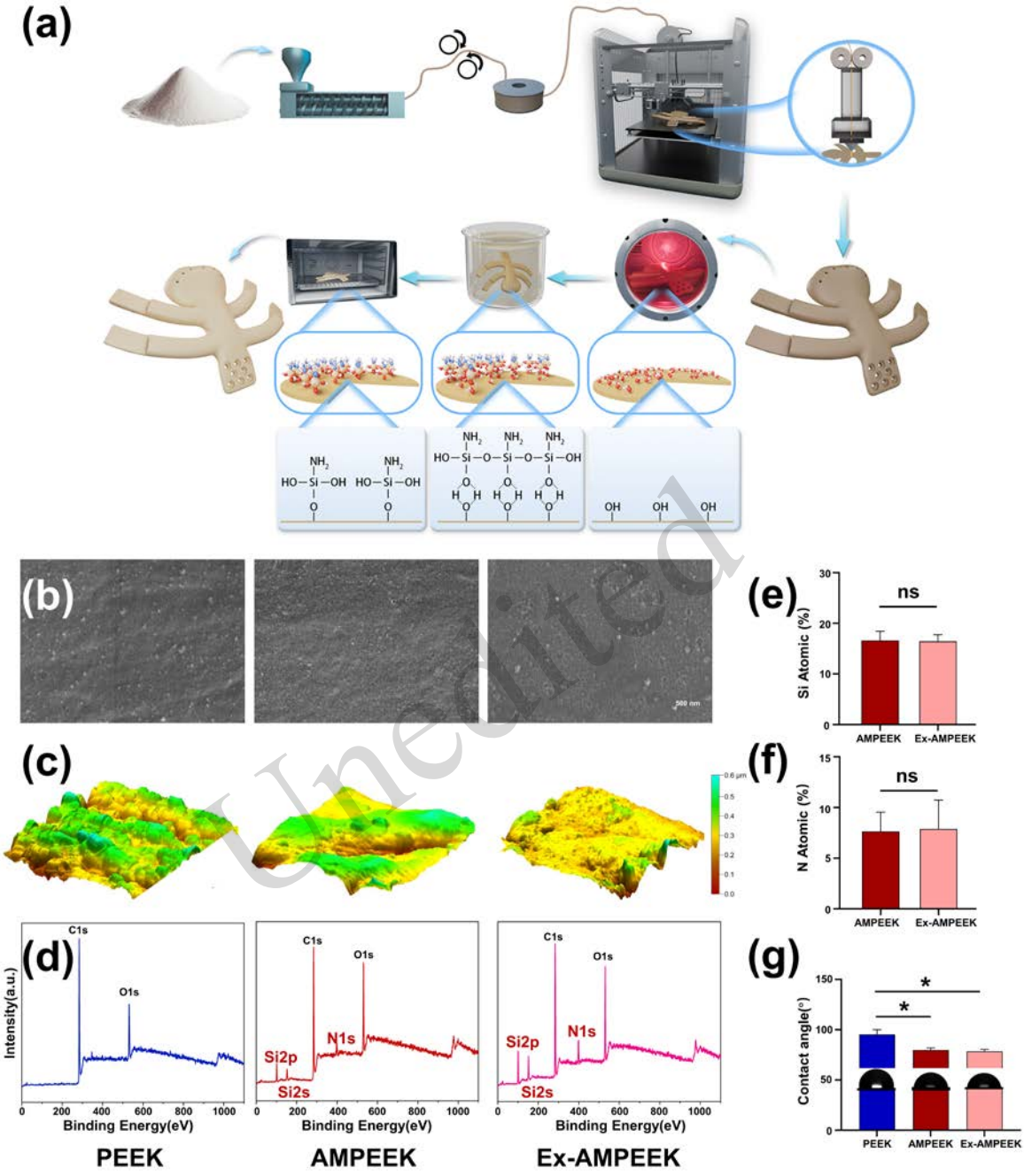

Fig. 1 Schematic diagram of implant surface modification (a) and characterization of implants. (b) SEM images of PEEK samples, AMPEEK samples and Ex-AMPEEK samples. (c) AFM 3D images of the surface topography of PEEK samples, AMPEEK samples and Ex-AMPEEK samples (the surface height corresponds to the color in the scale bars). (d) Total energy spectrum of X-ray photoelectron spectroscopy of PEEK, AMPEEK and AMPEEK samples. (e) Si content on the surface of AMPEEK and Ex-AMPEEK samples. (f) N atom content on the surface of AMPEEK and Ex-AMPEEK samples. (g) Water contact angles of PEEK, AMPEEK and Ex-AMPEEK samples (* represents $p < 0.05$).

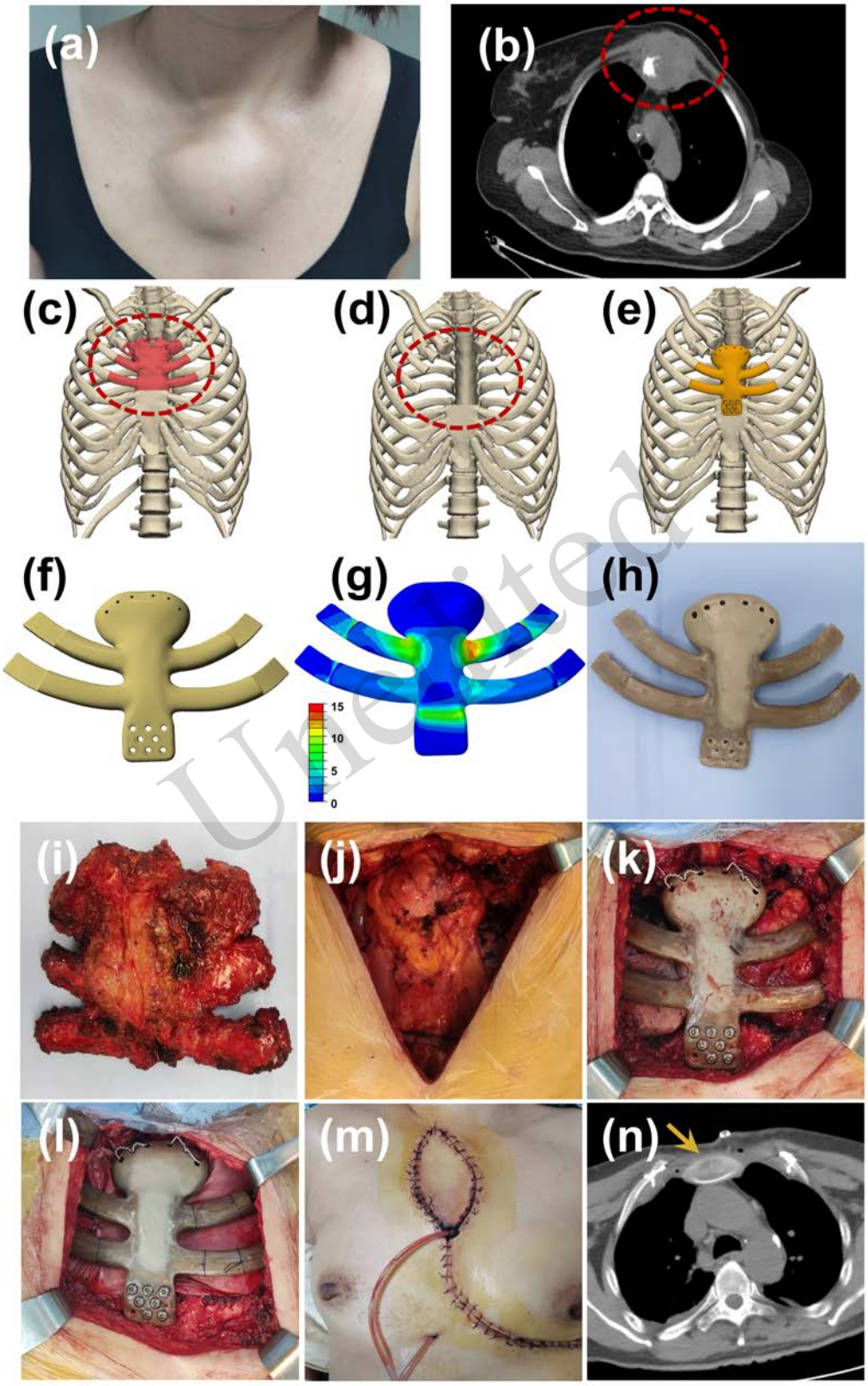

Fig. 2 Fabrication and surgical application of the implants. (a) Appearance of the tumor on the patient's chest wall. (b) CT findings of chest wall tumors (the superficial injection area is the chest wall tumor). (c) The resection range was designed after reconstruction of the patient's chest CT data (the marked area is the estimated resection area). (d) The extent of chest wall defect after tumor resection was simulated (the marked area shows the chest wall defect). (e) Simulation of the steroid-rib prosthesis for bony repair of the defect area. (f) Design drawing of 3D-printed implant. (g) Finite element analysis (FEA) of implants. (h) Profile display of the amino-modified PEEK implants. (i) Extended resection of the sternal tumor. (j) Chest wall defect after tumor resection. (k) 3D-printed steroid-rib for bony reconstruction. (l) Pleural reconstruction with artificial mesh. (m) Soft tissue reconstruction. (n) Postoperative CT images (PEEK implant visible at the mark).

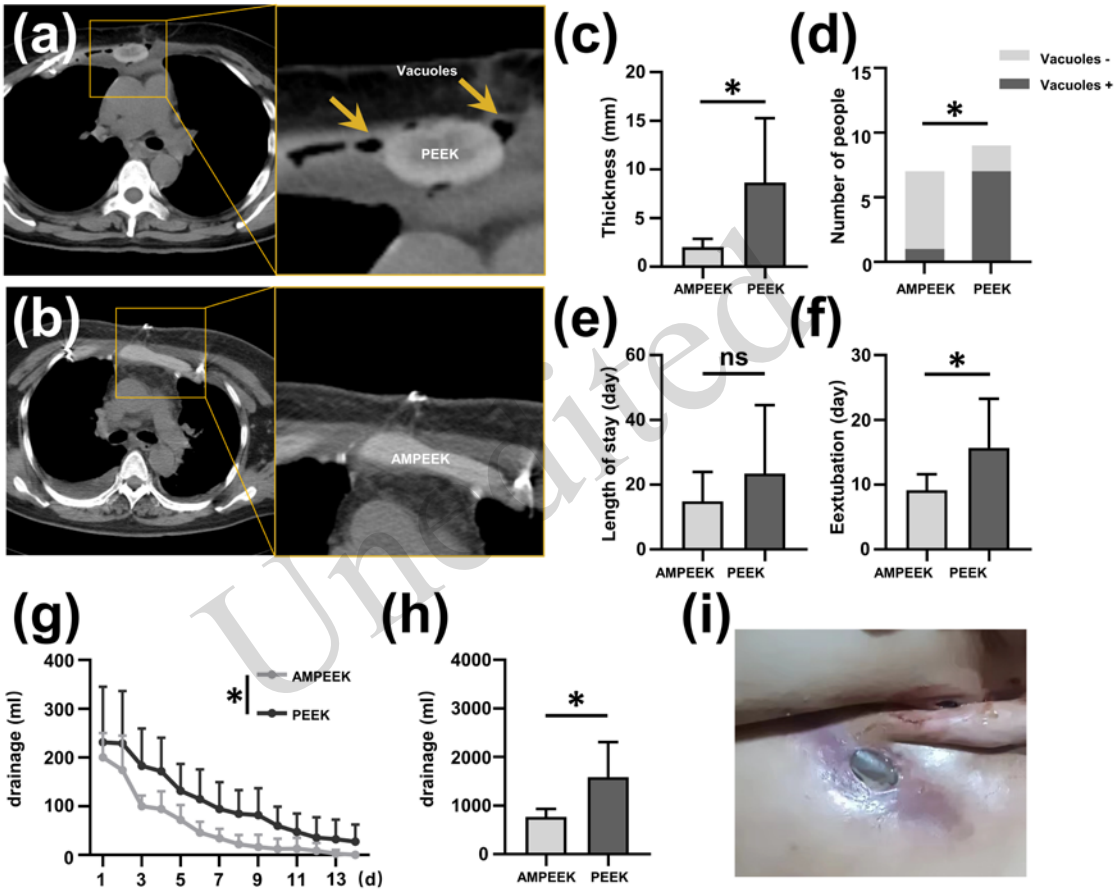

Fig. 3 Perioperative data of the patients. (a) CT image of PEEK group. (b) CT image of AMPEEK group. (c) Thickness of the low-density area around the implant. (d) Vacuoles around the implant. (e) Length of hospital stay of the patient. (f) Extubation time after surgery. (g) Changes in postoperative daily drainage volume. (h) Total drainage volume of postoperative patients. (i) Postoperative incision ulceration (* represents $p < 0.05$).

References

Cassari L, Zamuner A, Messina GML, et al., 2023. Bioactive peek: Surface enrichment of vitronectin-derived adhesive peptides. *Biomolecules*, 2(13):246. https://doi.org/10.3390/biom13020246

Chen TJ, Jinno Y, Atsuta I, et al., 2022. Current surface modification strategies to improve the binding efficiency of emerging biomaterial polyetheretherketone (peek) with bone and soft tissue: A literature review. *Journal of Prosthodontic Research*, 67(3):337-347. https://doi.org/10.2186/jpr.JPR_D_22_00138

Dondani JR, Iyer J, Tran SD, 2023. Surface treatments of peek for osseointegration to bone. *Biomolecules*, 13(3) https://doi.org/10.3390/biom13030464

Hu C, Ashok D, Nisbet DR, et al., 2019. Bioinspired surface modification of orthopedic implants for bone tissue engineering. *Biomaterials*, 219 https://doi.org/10.1016/j.biomaterials.2019.119366

Liu X, Huang LJ, Zhang H, et al., 2021. Facile amidogen bio‐activation method can boost the soft tissue integration on 3d printed poly‐ether‐ether‐ketone interface. *Advanced Materials Interfaces*, 8(19) https://doi.org/10.1002/admi.202100547

Liu YJ, Wang L, Zhang J, et al., 2025. A design strategy for long-term stability of porous peek implants by regulation of porous structure and in vivo mechanical stimulation. *Bio-Design and Manufacturing*, 8(2):275-287. https://doi.org/10.1631/bdm.2400259

Ma TT, Zhang JJ, Liu XY, et al., 2024. Effects of combined modification of sulfonation, oxygen plasma and silane on the bond strength of peek to resin. *Dental Materials*, 40(4):e1-e11. https://doi.org/10.1016/j.dental.2024.02.001

Oladapo BI, Zahedi SA, Ismail SO, et al., 2021. 3d printing of peek and its composite to increase biointerfaces as a biomedical material- a review. *Colloids and Surfaces B: Biointerfaces*, 203 https://doi.org/10.1016/j.colsurfb.2021.111726

Panayotov IV, Orti V, Cuisinier F, et al., 2016. Polyetheretherketone (peek) for medical applications. *Journal of Materials Science: Materials in Medicine*, 27(7) https://doi.org/10.1007/s10856-016-5731-4

Sun CN, Dong EC, Tian YC, et al., 2024. Functional biomimetic design of 3d printed polyether-ether-ketone flexible chest wall reconstruction implants for restoration of the respiration. *Materials & Design*, 237 (2024):112574. https://doi.org/10.1016/j.matdes.2023.112574

Wang BY, Huang MH, Dang PR, et al., 2022a. Peek in fixed dental prostheses: Application and adhesion improvement. *Polymers*, 14(12) https://doi.org/10.3390/polym14122323

Wang L, Yang C, Sun C, et al., 2022b. Fused deposition modeling peek implants for personalized surgical application: From clinical need to biofabrication. *International Journal of Bioprinting*, 8(4) https://doi.org/10.18063/ijb.v8i4.615

Wang L, Yan XL, Li J, et al., 2024. Outcomes following the excision of sarcoma and chest wall reconstruction using 3d printed implant. *iScience*, 27(2) https://doi.org/10.1016/j.isci.2023.108757

Wei X, Wang M, Pan Y, et al., 2023. Influence of fabrication method on the biological properties of modified peek. *Dental Materials Journal*, 42(1):72-78. https://doi.org/10.4012/dmj.2022-115

Wu H, Guo Y, Guo W, 2023. Effect of carbon-fiber-reinforced polyetheretherketone on stress distribution in a redesigned tumor-type knee prosthesis: A finite element analysis. *Frontiers in Bioengineering and Biotechnology*, 11 https://doi.org/10.3389/fbioe.2023.1243936

Zhang Z, Zhang X, Zheng Z, et al., 2023. Latest advances: Improving the anti-inflammatory and immunomodulatory properties of peek materials. *Materials Today Bio*, 22 https://doi.org/10.1016/j.mtbio.2023.100748

Zhu Y, Cao Z, Peng Y, et al., 2019. Facile surface modification method for synergistically enhancing the biocompatibility and bioactivity of poly(ether ether ketone) that induced osteodifferentiation. *ACS Applied Materials & Interfaces*, 11(31):27503-27511. https://doi.org/10.1021/acsami.9b03030

Supplementary information:

Methods and Results; Figs. S1-S2