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Preparation of Graphene-Nylon Composite Materials and Their Application in Spinal Scoliosis Corrective Braces

Zhang Qian[1,a,*], Wu Hailin[1], Wen Ping[2], Wang Hao[2], Liu Chun[1], Deng Manjiao[1], Yuan Kaijie[1]

[1]Grahope New Material Technology Inc., Shenzhen, Guangdong, 518063, China
[2]Maternal and Child Healthcare Medical Research Institute, Shenzhen Maternity and Child Healthcare Hospital, Southern Medical University, Shenzhen, Guangdong, 518100, China
[a]zhangq@szxiwang.cn
**Corresponding author*

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Abstract: Initially, a graphene dispersion solution was obtained by aminating graphene oxide, which was synthesized via an improved Hummers method. Specific particle size nylon powder, modified graphene dispersion liquid and Chemical auxiliaries were added to a high-pressure vessel at a certain ratio under specific temperature and pressure conditions. The amide groups on the surface of the graphene nanoflakes reacted with the nylon powder to form a complete coating, resulting in shape-regular and uniform particle sizes of graphene-nylon composite powders. Subsequently, utilizing biomechanical simulation combined with selective laser sintering (SLS) process, we shaped-sintered the three-dimensional orthopedic braces. We optimize the brace printing process by taking into account material properties, laser power, predicted temperature, powder thickness, scanning speed and additives. Furthermore, the performance and application effect of the orthopedic braces are verified through properties tests and clinical trials. The results show that the maximum tensile strength was 45MPa, and the maximum bending modulus was 1232MPa, the heat distortion temperature was 144°C, No obvious changes were observed in the sample after more than 5,000 times of opening and closing tests with the opening angle ≥120°. Moreover, the results of clinical trial show that before and after the intervention, the average scoliosis angle of the patients decreased from 13.36 degrees to 6.21 degrees and more than 50% of the patients decreased from 12.68 degrees to 3.85 degrees, which proves the clinical effectiveness of spinal scoliosis corrective brace based on the graphene-nylon composite material.

1. Introduction

Scoliosis is a deformity of the three-dimensional structure of the spine, Its diagnostic criterion is that the Cobb Angle of scoliosis is greater than 10°, which usually leads to changes in the structure and biomechanics around the vertebral bodies[1]. One type of idiopathic scoliosis is the most common, especially with the highest incidence among teenagers. Global epidemiological studies have found that the incidence of adolescent idiopathic scoliosis in Italy ranges from 0.47% to 5.20%, while in some parts of Asia, it is approximately 2%[2-4]. In China, the prevalence rate of scoliosis is 1.2% among teenagers aged 10 to 18, the prevalence rate among females is higher than that among males, the prevalence rate among adolescents in the north is higher than that in the south, and it has shown an increasing trend year by year in recent years[1]. Studies have shown that corrective brace can effectively improve and treat spinal scoliosis, particularly in patients with a Cobb Angle ranging from 15 to 30 degrees[5-7].

The traditional spinal scoliosis corrective brace commonly used is primarily made of plaster material, which has a complex production process, limited breathability, and challenges in achieving lightweight. Its mechanical and physical properties are subpar, leading to discomfort for patients wearing it. The design rationality of the brace heavily relies on the expertise of professional orthopedic technicians and due to manufacturing errors, it is usually necessary to repeatedly adjust the brace structure during actual use. With the widespread adoption of 3D printing technology in the medical industry, spinal scoliosis corrective braces based on digital design can be achieved through 3D printing process technology, which can enhance manufacturing accuracy as well as the brace's lightness and breath-ability[8-10]. However, there are currently no suitable 3D printing materials specifically developed for spinal scoliosis corrective brace available on the market. According to orthopedic technicians' experience, nylon material-based spinal scoliosis corrective brace produced using selected laser sintering methods are currently preferred choices. Nevertheless, this processing method has not been widely adopted due to poor weather resistance and wall thickness issues associated with braces produced using nylon powder laser sintering methods.

Nylon microballs represent a new type of high-performance advanced material with broad application prospects in various fields including biomedicine, laser sintering 3D printing, and light diffusion. Considering that graphene and polymer nanomicroballs share similar sizes and possess high specific surface areas, polymer/graphene composite materials were synthesized through mixing graphene with microballs to avoid traditional melt blending disadvantages and form an interpenetrating network (IPN) structure, the dispersed uniformly structure within the polymer matrix can significantly enhance nanocomposite material performance. Ma Meng's group prepared high-performance composite materials based on rGO(reduced Graphene Oxide) and PA6 (Polyamide 6) using a solution co-mixing and hot pressing method, which resulted in excellent electrical performance due to the successful formation of an isolation structure[11]. Fu Xubing et al.'s synthesis of PA6 microballs wrapped with GO (Graphene Oxide) via reaction-induced phase separation and the peeling adsorption method led to the formation of a three-dimensional network structure within the PA6 matrix, resulting in improved electrical and mechanical properties compared to traditional polymer/graphene composite materials[12]. Although graphene's high specific surface area coupled with strong mechanical properties theoretically can lead to significant improvements in material comprehensive performance upon application, dispersion remains a primary challenge. Modifying nylon powder with carbon-based auxiliaries such as graphene or carbon nanotubes enhances several key properties including tensile strength, elongation at break, Young's modulus, bending modulus, thermal stability, moldability, fatigue resistance, heat deflection temperature thereby improving product durability[13]. Zhang Yunhai et al.'s development of an efficient environmentally friendly functionalized oxidized graphene (FGO) preparation method utilized within PA6 composite functional fiber resulted in substantial enhancements across multiple parameters including tensile strength, tensile elastic modulus UV protection factor antibacterial performance indicating effective bacterial invasion prevention capabilities[14]. Qingshi Meng's Group[15] demostrated that graphene platelets is an effective nanofiller to prepare PA polymer nanocomposites with high mechanical, electrical, thermal properties in the SLS process.

However, there remain challenges in obtaining high-performance and stable 3D-printed graphene-nylon composites in fact, including graphene dispersion, the composite process of graphene-nylon materials, printing processes and etc. Furthermore, there are limited reports on the application of graphene-nylon composites in the correction and treatment of scoliosis. In this study, graphene-nylon composites were successfully prepared by effectively dispersing graphene and modifying nylon. And then by integrating biomechanical simulation design with Selective Laser Sintering (SLS) 3D printing technology, three-dimensional corrective back braces were printed out successfully using composite powder materials and used in clinical trials for scoliosis correction. The results of Clinical trials demonstrated that the brace developed in this research offers a high degree of patient-specific fit, significant corrective efficacy, and enables truly customized, precise, and digitally driven treatment plans.

2. Experiments

2.1. Modification and Preparation of Graphene

The Hummers method was employed to modify and prepare the graphene [16-18]. Graphite powder was added to a mixture of sodium nitrate and concentrated sulfuric acid, followed by the slow addition of potassium permanganate while stirring for 30 minutes. The mixture was heated to 98°C and reacted until it turned bright yellow. Subsequently, 30% hydrogen peroxide was added to neutralize the mixture, which was then sequentially washed with a 5% hydrochloric acid solution and deionized water until the pH of the separated liquid reached 7. After sonication, centrifugation, washing, and drying steps, graphene oxide powder was obtained. In this process, the mass ratio of graphite to sodium nitrate to potassium permanganate remained at 1:1:3; for every gram of graphite used, 20 ml of concentrated sulfuric acid were added.

Graphene was dispersed in N,N-dimethyl formamide(DMF), and dichlorosulfoxide was added dropwise to the mixture under an ice-water bath for a 2-hour reaction period. The resulting solution was then heated to 70 °C and stirred continuously for 36 hours. Following this, the mixture was filtered using a DMF solution and subsequently mixed with a dodecanediamine solution. This new mixture underwent reaction in an ice bath for four hours before being filtered once more and dried to obtain amino-functionalized graphene powder. Throughout this step, the mass ratio between graphene oxide, DMF, and dichloroform remained at 1:90:40. Finally, hexadecanoyl trimethyl ammonium chloride along with graphene powder were introduced into isopropanol in equal masses followed by sonication for two hours in order to obtain a modified dispersion liquid.

2.2. The Specific Process of Preparing Graphene Nylon Powder Composite

The specific process of preparing graphene nylon powder composite is as follows:

1) 100 parts of modified graphene dispersion liquid, 1000 parts of nylon 12, 5 parts of antioxidant, 0.05 parts of silane coupling agent, and 4500 parts of distilled water are added to the polymerization reactor for mutual mixing. The reactor is pressurized to 1MPa with nitrogen and the solution is continuously stirred at high speed(630 rpm). And then the temperature was raised to 145 °C and maintain it for one hour until nylon 12 is completely dissolved. After complete dissolution, release the high pressure and cool the temperature at a rate of 4°C/min to room temperature in order to obtain a suspension of micron-sized nylon particles.

2) The suspension of micron-sized nylon particles was freeze-dried and then sieved through a mesh screen with a size of 200-mesh. Finally, graphene/nylon composite powder materials were obtained .

2.3. Graphene/nylon Powder Molding

In this study, we perform molding of graphene/nylon powder using selective laser sintering (SLS) forming process[19-21]. We investigate the influence of parameters such as powder layer thickness, preheat temperature, laser sintering power, and scanning speed on the formation process of graphene/nylon powder material. Furthermore, we analyze and test the mechanical and thermal properties of composite material samples obtained.

2.4. Digital Corrective Brace Design

For digital orthopedic design purposes, surface data from human body is obtained using an optical 3D scanner while spinal data is acquired through X-ray or CT instruments[22]. Additionally manual measurements are taken for key data such as waist circumference, bust circumference, and height from armpit to iliac crest. The functional three-arc and four-arc spinal curvature types based on Schroth classification method[23, 24] are divided into seven types: 3CH, 3CTL, 3CN, 3CL, 4C, 4CL and 4CTL. These types correspond to specific features of spinal scoliosis location and brace design methods. Successful design cases are classified according to the above seven types combined with key feature information of patient's chest circumference, waist circumference, distance from armpit to iliac crest, and Cobb angle, etc.

The Rodin 4D software employs the finite element method to simulate stress and strain distribution in the spine when a spinal scoliosis correction brace is used[25-27]. This simulated analysis helps predict the forces and stresses exerted on the brace during actual usage, thereby optimizing its design for enhanced durability and comfort.

2.5. Clinical Observation of 3D Printed Scoliosis Corrective Brace

In this study, personalized treatment with a 3D printed spinal scoliosis correction brace was given to 8 subjects (7 females and 1 male) aged between 9 to 17 years (with an average age of 12.25 years). X-ray observations[21] were conducted at least 24 hours after removing the brace to accurately predict posterior vertebral displacement in the natural state of the spine.

3. Results and Discussion

3.1. Morphology Analysis of Graphene in Dispersions

Graphene was prepared by a modified hummers method. Fig. 1 shows the sample physical picture and microstructure images of the graphene. Fig. 1 a) show that the morphology of graphene before dispersion, indicating severe agglomeration of graphene. The sample picture of the graphene after dispersion in Fig. 1 b) demonstrate that the prepared sample has good dispersion. The microstructure of the sample was characterized by scanning electron microscopy following the testing standards "Good Practice Guide No.145 Graphene Structural Characterization", as depicted in Fig. 1 c), which showed that graphene presents a two-dimensional sheet-like structure with with a sheet size of approximately 2.73μm*2.36μm, and has good dispersibility, without agglomeration. The size distribution of the sheet diameter was further characterized, as shown in Fig.1 d) and e), The average diameter range of graphene flakes is between 900nm-6100nm, and the geometric mean is ranging from 900nm-5700nm.

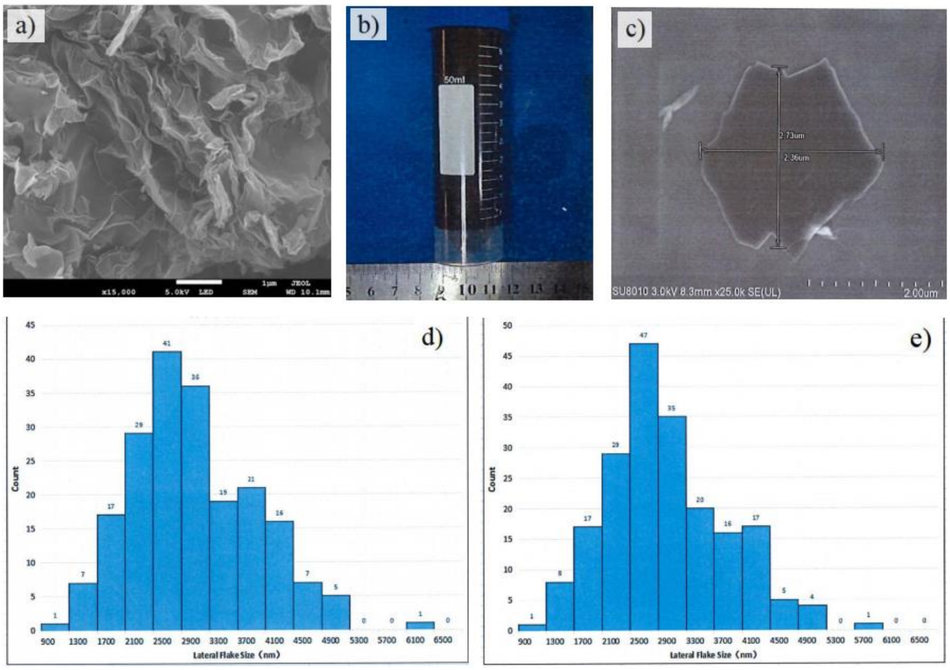
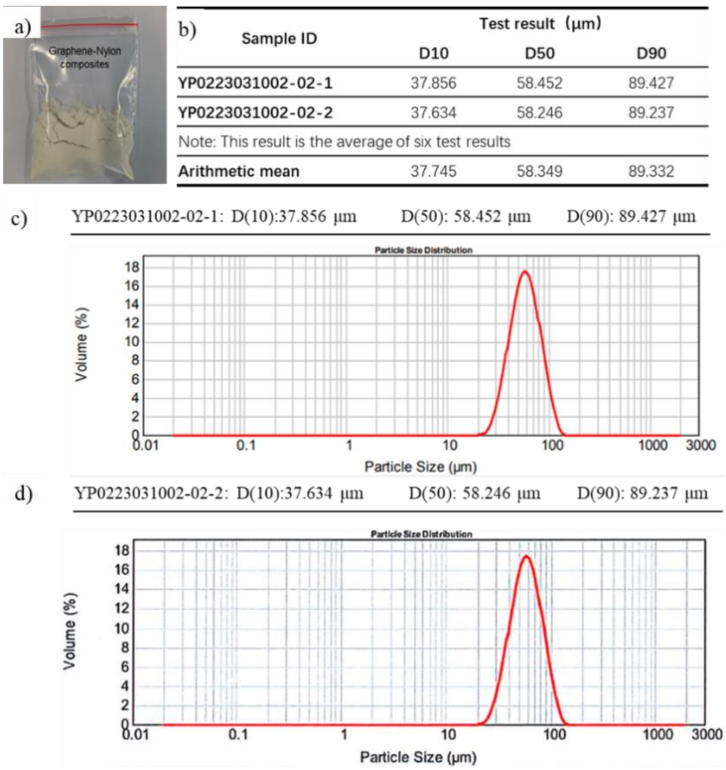


Fig. 1 Graphene dispersion solution. a) SEM image of graphene before dispersion; b) Photograph of graphene dispersion solution, c) SEM image of graphene after dispersion. d) Arithmetic mean distribution diagram and e) Geometric mean distribution diagram of the diameter size of graphene sheets.

3.2. Particle Size Analysis of Graphene/nylon Composite Powder



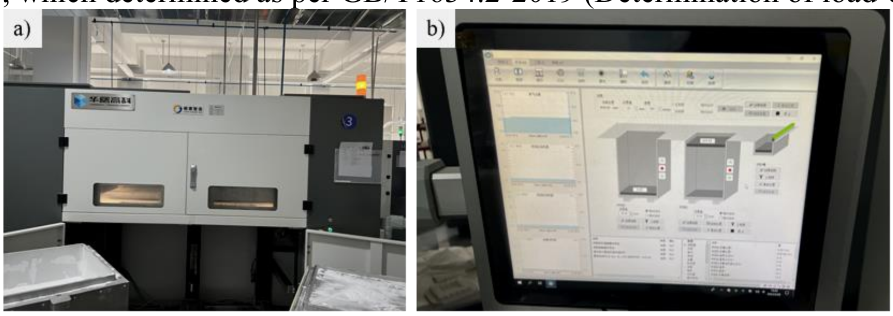
Sample ID	Test result (μm)		
	D10	D50	D90
YP0223031002-02-1	37.856	58.452	89.427
YP0223031002-02-2	37.634	58.246	89.237
Note: This result is the average of six test results			
Arithmetic mean	37.745	58.349	89.332

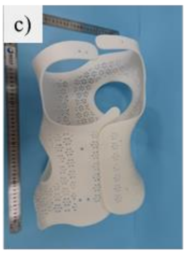
Fig. 2 Particle size distribution of graphene/nylon composite powder.

Graphene/nylon 12 composites were fabricated by employing nylon 12 as the polymer matrix and graphene as the nanoscale filler through a high-temperature solution blending process, with the objective of enhancing the thermal stability and mechanical performance of nylon 12. The sample picture of the composites is showed in Fig. 2a). The dispersion of the synthesized composites is a key indicator for 3D printed products. Therefore, Fig. 2 characterizes the particle size distribution of the composites. In accordance with "GB/T19077-2016 Particle Size Analysis by Laser Diffraction Method," particle size analysis was performed using an MS2000 laser particle size analyzer for determining particle size distribution within graphene/nylon composite powder. The obtained results revealed D10 value as 37.75μm, D50 value as 58 .35μm, and D90 value as 89.3μm illustrated in Fig. 2 b-d), it can be seen that 90% of the particle sizes of the composite powder are all less than 90μm, which is beneficial to the 3D printing process.

3.3. Analysis of the Molding Process and Properties of Graphene/Nylon Composites

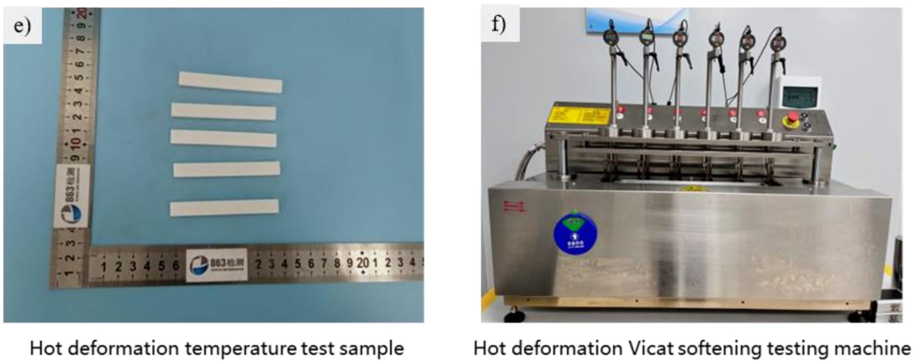
The molding process of the graphene/nylon composite material through 3D printing based on the selective laser sintering (SLS) process is shown as Fig. 3a-c). This process can form both simple structures and complex structures, which can meet various application requirements. The optimized parameters for the SLS process are presented in Fig. 3d). Fig. 3e) and f) characterized the thermal deformation test of the printed specimen, it is proved that the heat distortion temperature was in a value of 144℃, which determined as per GB/T1634.2-2019 (Determination of load-defo





d)

Parameter Item	Gradient Spread
depth of stratum	0.08-0.15mm
laser power	40-100W
laser velocimeter	800mm/s
Squeegee Speed	200mm/s
Temperature of the construction platform	80-120℃



Hot deformation temperature test sample

Hot deformation Vicat softening testing machine

Fig. 3 a) and b) the photos of 3D printing equipment; c) the specimen photo by 3D printing; d) the printing parameters; e) and f) Thermal deformation test of graphene/nylon material specimen.

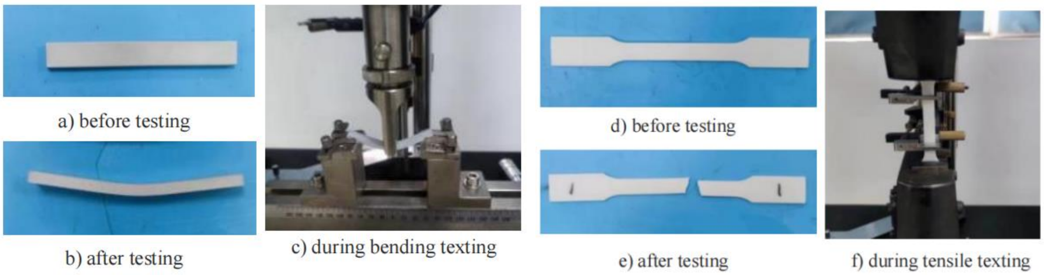


Fig. 4 bending test a) before bending, b) after bending, c) during bending, and tensile test d) before stretching, e) after stretching, f) during stretching.

The bending strength and modulus were measured using a microcomputer-controlled universal testing machine according to GB/T 9341-2008 (Determination of bending properties of plastics) in Fig. 4a-c), which yields values of 45 MPa for bending strength and 1232 MPa for bending modulus. Molding temperature of plastics - Part 2: Plastics and rigid rubbers) using a heat distortion Vicat tester. Furthermore, The tensile strength, elongation at break, and tensile modulus of the printed samples produced by SLS were determined using a microcomputer-controlled universal testing machine in accordance with GB/T 1040.2-2022 (Determination of tensile properties of plastics- Part 2: Test conditions for molded and extruded plastics), as shown in Fig. 4d-f). The results indicated a tensile strength of 40 MPa, an elongation at break of 31%, and a tensile modulus of 1386 MPa. Therefore, the graphene/nylon composite samples prepared by selective laser sintering printing technology have good thermal stability and mechanical properties.

3.4. Digital Simulation Design of Graphene/nylon Composite Material Corrective Braces

In order to better apply graphene/nylon composite materials in the scoliosis corrective brace, the corrective brace was designed through digital precise simulation. The finite element analysis software (Rodin 4D) was used to simulate the pressure and force conditions exerted on the patient's trunk by the corrective brace in the actual wearing state, as depicted in Fig. 5. Specifically speaking, the digital simulation process of the corrective brace in Figure 5a) is shown as follow: a-Spinal modeling: Firstly, the patient's spinal images are obtained through X-ray films (frontal and lateral views), and the severity of scoliosis is determined by the Cobb angle measurement method. Key data such as spinal curvature and deformity degree are extracted from the X-ray films to provide a basis for subsequent three-dimensional analysis. The 3-matic software is used to model the spine and intervertebral discs, and finally a spinal model is obtained. b-Surface model modeling: The patient's surface data is obtained through 3D scanning, and the data is smoothed and boundary trimmed to obtain a surface model. c-Establishment of three-dimensional spinal model: The spinal model and surface model are fitted to obtain a digital trunk model. d-brace design: The trunk model is edited and modified using brace design software to obtain a digital brace design. Further pressure simulation and Stress simulation analysis is conducted through finite element software, as shown in Figure 5b). The finite element analysis (FEA) software is used to superimpose the digital brace design and the trunk model, and parameters are set according to the physical properties of the human body and the brace material to obtain the pressure simulation of the digital brace design on the patient's surface. Furthermore, Stress simulation analysis was carried out, as shown in Figure 5c). By selecting the position of the spinal segments, the cross-section was observed under the intervention of the main thrust and counter force, compared with the original changes in the trunk, and the structural parameters of the brace (such as the correction position force point area, force application size, anti-rotation force coupling, etc.) were adjusted in real-time. The fitting effect and stress distribution after the adjustment were fed back, thereby further optimizing the design of the corrective brace.

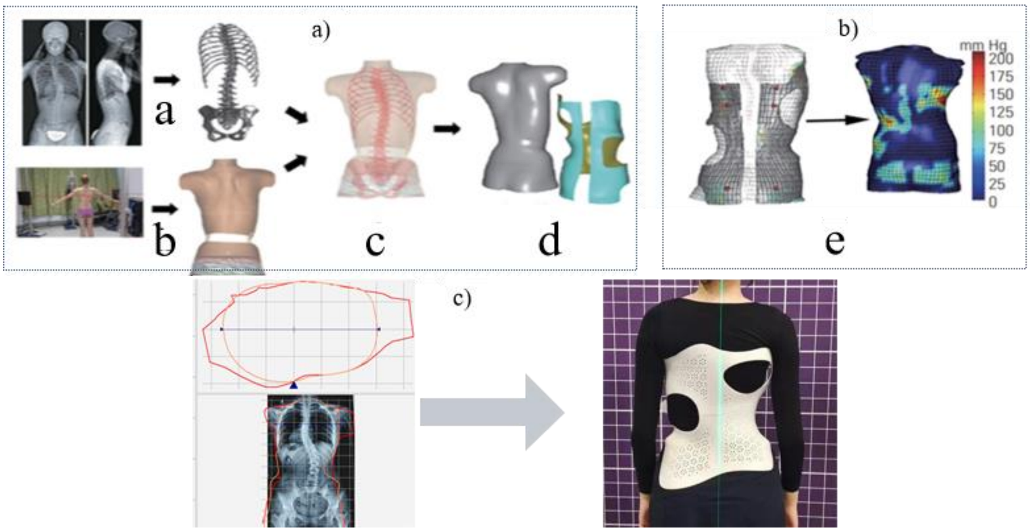
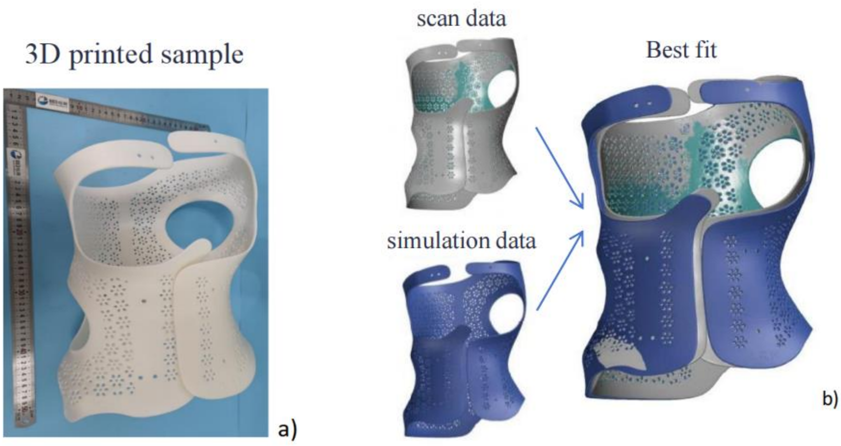


Fig. 5 3D modeling analysis of digital scoliosis orthosis. a)The digital simulation process of the orthopedic brace; b)pressure simulation through finite element software; c)Stress simulation analysis.

The fitting comparison process between scanned data and CAD data mainly includes the following steps: data collection and pre-processing, import and matching of CAD design models, deviation analysis and adjustment of the best fit, and evaluation of fitting accuracy. In order to evaluate the fitting effect, the fitting accuracy of the brace was evaluated and shown in Fig.6. Specifically, the key positions of the corrective back frame, including length, diameter and thickness, etc., were measured specifically. The actual measured values were compared with the nominal design values, the error values were calculated and compared with the allowable deviation range. The results were shown in the Fig.6c). According to the results, As per "WI-143-003 Computer-Aided Verification Procedure Manual," simulation accuracy for 3D scanning and dimensional inspection tests should be ≥80%, while design and manufacturing tolerance should be≤±5%, indicating a good fitting effect.

Meanwhile, According to "T/CAMDI 072-2021 Custom Additive Manufacturing Spinal Scoliosis Corrective Brace," the 3D printed spinal scoliosis corrective brace based on graphene/nylon composite material has successfully passed the fatigue inspection. It demonstrated that no obvious changes of the sample were observed after a closing/opening frequency of ≥5000 times with a fatigue test angle of 120° in Fig.7.



Element	Property	Nominal	Actual	Rate of change limit (%)	Tol±	Dev	Conclusion
Spot1#	length（L）	+342.780	+334.468	≥80%	±68.556	-8.312	PASS
Spot2#	length（L）	+350.540	+348.356	≥80%	±70.108	-2.184	PASS
Spot3#	length（L）	+76.860	+77.474	≥80%	±15.372	+0.614	PASS
Spot4#	length（L）	+100.020	+100.323	≥80%	±20.004	+0.303	PASS
Spot5#	curve length	+358.029	+342.257	≤±5%	±17.901	-15.772	PASS
Spot6#	diameter（ φ ）	+4.880	+4.770	≤±5%	±0.244	-0.110	PASS
Spot7#	length（L）	+3.400	+3.404	≤±5%	±0.170	+0.004	PASS
Spot8#	length（L）	+55.100	+54.715	≤±5%	±2.755	-0.385	PASS
Best-fit alignment, Unit:mm							c)

Fig. 6 Orthopedic simulation accuracy test. a) Test samples; b) Simulation schematic diagram; c) Simulation test data

a) before testing b) during texting c) after testing

Fig. 7 5000-time fatigue test of the orthosis. a) Before the test; b) In the opening and closing test; c) After the test

3.5. The Clinical Observation Trial of Digital Corrective Braces in the Spinal Scoliosis Correction

Digital corrective braces have further been applied in clinical trials on adolescent patients with scoliosis. Fig. 8 shows the personal basic information and experimental data of the corrective brace test groups of multiple patients. It can be seen from the figure that there were a total of eight participants in the experimental group, including seven females and one male. The age distribution shows that the youngest participant was 9 years old, the oldest was 17 years old, the average age was 12.25 years old, and the standard deviation was 2.76 years old, reflecting that this project covered a wide range of adolescent age groups. Enrollment and screening status: through detailed screening procedures, it was ensured that each subject meet the enrollment criteria, including medical history review, severity assessment of scoliosis, and comprehensive assessment of the patient's physical condition.

Brace design and adaptation: The design and adaptation of digital scoliosis correction braces for 8 subjects have been completed. Each subject received a tailor-made corrective brace through high-precision 3D scanning and personalized design software. The successful design cases were classified into seven types based on key feature information in Fig. 8, such as the patient's chest circumference, waist circumference, distance from armpit to iliac crest, and Cobb angle. This categorization aims to facilitate efficient retrieval during new design requirements while adhering to spinal scoliosis brace design principles.

It can be known from the clinical trial results after the intervention that the degree of scoliosis of the subjects decreased significantly, as shown in Fig. 9. From the result of Clinical trial statistics in Fig. 9a) , It can be known that the average scoliosis angle in the subjects showed a reduction from 13.36 degrees to 6.21 degrees before and after intervention, indicating an overall improvement. Moreover, after treatment with the graphene/nylon composite corrective brace, the Cobb Angle of 50% of the patients decreased from 12.68° to 3.85°, and that of more than 75% of the patients decreased from 15.87° to 6.03°, further confirming the effectiveness of digital corrective brace in the treatment of scoliosis. Specially, Fig. 9b) shows the patient case with the most significant therapeutic effect. The Cobb Angle of scoliosis of the patient before the initial treatment was significantly larger (example value: 21.27° on the left side). After a period of treatment with the 3D printed graphene/nylon composite powder corrective brace, the Cobb Angle was significantly decreased (gradually decreased during the prediction period shown in the middle figure); In the final test after the treatment course ended, the Cobb Angle decreased to a level close to normal (as shown in the right illustration, 8.81°, only when it is 10° or above normal is defined as scoliosis). This patient achieved an excellent treatment effect, significantly improving the patient's posture and comfort and returning to normal values. The corrected values (21.27°→8.81°) reflect the significant effectiveness of the treatment plan, confirming the application prospects and clinical value of this material and design plan in the treatment of scoliosis.

a) Basic information of clinical trial volunteers

ID	Name	Screening time	Be enrolled or not	Gender	Age	The degree of curvature before correction	The degree of curvature after correction	Whether to confirm the comfort on site	Voluntarily wear the brace and have an X-ray taken at our hospital on that day
AIS001	LEE X Y	20231112	YES	Female	9	6.00	1.00	√	At the Second Hospital
AIS003	WU Z T	20231112	YES	Male	14	5.89	2.05	√	√
AIS004	CAO X Y	20231112	YES	Female	9	12.96	3.03	√	√
AIS006	WU Y H	20231112	YES	Female	17	14.07	3.97	√	√
AIS009	YE J J	20231123	YES	Female	13	21.27	8.81	√	√
AIS012	HOU Q Y	20231209	YES	Female	16	12.40	3.72	√	√
AIS019	ZENG K C	20240125	YES	Female	11	9.10	5.10	√	√
AIS020	HE Y T	20240125	YES	Female	11	25.20	22.00	√	√
AIS021	ZHANG Q W	20240221	YES	Female	18	32.00	-	√	×

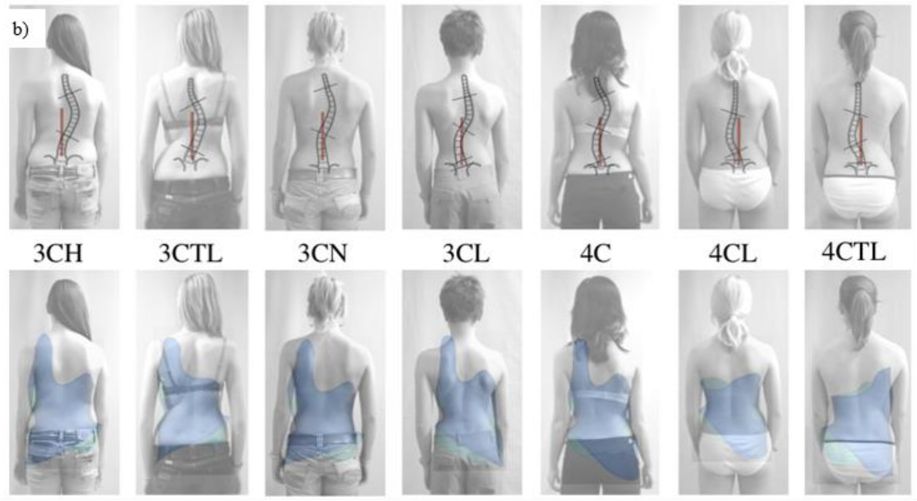
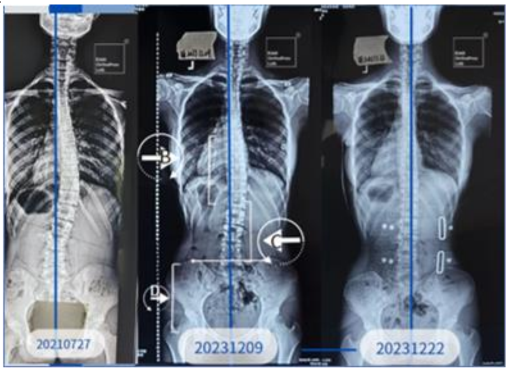


Fig. 8 a) Basic information of clinical trial volunteers and b) Schroth's scoliosis classification and orthopedic shape.

Statistical index	Average value before treatment	Average after treatment
AVG	13.36°	6.21°
STD	6.89°	6.79°
MIX	5.89°	1.00°
25% quartile	8.33°	2.79°
50% quartile	12.68°	3.85°
75% quartile	15.87°	6.03°
MAX	21.27°	8.81°



a) trial statistics　　　　b)remarkable case

Fig. 9 a) Clinical trial statistics results; b) One of the most remarkable cases in clinical orthopedic treatment

4. Conclusion

In conclusion, nylon 12 was modified with graphene as the nano-filler, and the corrective brace were fabricated through the 3D printing and selective laser sintering process, the thermal and mechanical properties of the brace were improved. Combined with digital precision simulation technology and 3D printing technology, graphene/nylon composite materials were formed into corrective braces and used in clinical trials for scoliosis. Through the results of clinical trials, it has been proved that its effect in correcting scoliosis is remarkable, thus demonstrating the application prospects and clinical value of this material in the treatment of scoliosis.

The average size of graphene sheets in the modified dispersion liquid falls in the range of 900nm-6100nm for arithmetic mean and the range of 900nm to 5700nm for geometric mean. The particle size distribution of graphene/nylon powder is as follows: D10 at 37.75μm, D50 at 58.35μm, and D90 at 89.3μm.

Graphene/nylon composite materials exhibit a maximum tensile strength of 40MPa, maximum tensile modulus of 1386MPa, maximum elongation at break of 31%, maximum bending strength of 45MPa, maximum bending modulus of 1232MPa, and a heat deflection temperature of 144℃.

For the corrective brace: In the fatigue test item, the sample has undergone more than 5000 cycles of opening and closing with an opening angle≥120° without showing any obvious changes in appearance; In the simulation accuracy test for dimensional detection using three-dimensional scanning technology, it achieves an accuracy level ≥80% with design and manufacturing error ≤±5%.

Results from pre-and post-intervention measurements indicate that after utilizing digital corrective brace treatment, the average degree of scoliosis decreased from 13.36 degrees to 6.21 degrees while the Cobb angel of more than 50% of the patients decrease from 12.68 degrees to 3.85 degrees, confirming the effectiveness of digital corrective braces in correcting scoliosis.

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