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Vascular ultrasound in the monitoring of vascular injury in patients after intravenous chemotherapy

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Abstract: This study investigated vascular injury incidence, symptoms, and changes in vascular wall thickness and blood flow in 140 chemotherapy patients. Vascular ultrasound and laboratory tests were conducted at 1 week, 1 month, and 3 months post-chemotherapy. Results showed that vascular injury incidence increased over time (12.9% at 1 week, 25.0% at 1 month, 34.3% at 3 months, $P<0.05$). Vascular wall thickness (IMT) thickened from 0.61±0.11 mm at baseline to 0.85±0.22 mm at 3 months ($P<0.01$) and vascular diameter increased from 2.34±0.22 mm to 2.55±0.33 mm at 3 months ($P<0.01$). Severe phlebitis incidence rose from 2.9% at 1 week to 7.1% at 3 months ($P<0.01$). Elevated CRP and D-dimer levels correlated with increased vascular wall thickness and thrombosis. Enhanced monitoring and personalized interventions are needed to reduce complications. Combining ultrasound and laboratory markers can improve assessment of chemotherapy-induced vascular injury.

Keywords: Chemotherapy; vascular injury; vascular wall thickness; phlebitis; abnormal blood flow; inflammation; thrombotic markers; venous access devices

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INTRODUCTION

Chemotherapy is an essential treatment for various malignant tumors, especially in the advanced stages of cancer, metastatic disease, and postoperative adjuvant therapy (Zeng *et al*., 2022; Xu *et al*., 2024; Qu *et al*., 2023). Intravenous chemotherapy is considered a common and effective method of drug administration, ensuring that drugs enter the bloodstream quickly and directly, thereby achieving rapid control of tumors (Wei *et al*., 2021; Aryal *et al*., 2023). However, the damage of chemotherapy drugs to blood vessels is not negligible and may accumulate with an increase in the number of chemotherapy sessions, leading to a series of clinical complications such as phlebitis, thrombosis, vascular sclerosis, and even severe venous ulcers and extravasation (Khanna & Khanna, 2023). Especially in the long-term chemotherapy process, these vascular injuries can significantly affect the patient's quality of life and even affect the implementation of subsequent treatment plans (Lustberg *et al*., 2023).

Monitoring of vascular injury is of great significance in reducing or preventing the damage of chemotherapy drugs to blood vessels (Mclaughlin *et al*., 2021). Currently, traditional vascular examination methods such as clinical symptom observation, local examination of venipuncture sites, and imaging examinations can assess the vascular status to some extent, but they have many limitations, especially in the identification of early vascular injuries (Wong *et al*., 2022). In recent years, vascular ultrasound, as a non-invasive, real-time, easy-to-operate, and dynamic observation of vascular structure changes technology, has been widely used in clinical practice (Zhang *et al*., 2023; Gao *et al*., 2021). Vascular ultrasound can clearly display indicators such as the thickness of the vascular wall, vascular diameter and blood flow velocity through high-resolution imaging, providing accurate vascular injury information for clinical physicians and aiding in real-time monitoring of vascular status (Yang *et al*., 2024; Tiwari *et al*., 2022).

The purpose of this study is to explore the application value of vascular ultrasound in the monitoring of vascular injury in patients after intravenous chemotherapy. By conducting vascular ultrasound examinations on patients undergoing venous chemotherapy, combined with clinical assessments and laboratory tests, we analyze the role of vascular ultrasound in early detection of vascular injury, assessment of injury severity and guidance for adjusting treatment plans. We hope that this study will further confirm the clinical application value of vascular ultrasound as an effective monitoring tool in vascular injury caused by chemotherapy drugs, providing theoretical basis and technical support for related clinical practices, improving patient treatment outcomes, reducing the incidence of vascular complications and enhancing the quality of life for patients.

MATERIALS AND METHODS

Study design

This study is a prospective cohort study aimed at exploring the application value of vascular ultrasound in monitoring vascular injury in patients after intravenous chemotherapy. The study subjects are cancer patients undergoing

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chemotherapy and their vascular injury during chemotherapy is regularly checked by vascular ultrasound, combined with clinical assessment and laboratory tests, to explore the sensitivity and accuracy of vascular ultrasound in evaluating vascular injury. This study was approved by the Xiamen Hospital of Sichuan University Ethics Committee (approval No. 2019-124-003) and all participants gave written informed consent

Study subjects

The study included patients who received intravenous chemotherapy for cancer at a tertiary hospital from January 2019 to December 2023. All patients voluntarily participated in this study and signed informed consent forms.

Inclusion Criteria: (1) Age between 18 and 75 years, both genders included. (2) Diagnosed with malignant tumors and requiring intravenous chemotherapy. (3) At least one intravenous chemotherapy session (vascular ultrasound examination is performed immediately after the first dose of chemotherapy). (4) Patients have good cooperation ability to follow the treatment plan and study protocol. (5) Patients with controlled hypertension and diabetes were included to reflect real-world clinical scenarios. Their conditions were stable and did not significantly impact the study outcomes.

Exclusion Criteria: (1) Patients with severe liver, kidney, heart, or other systemic diseases affecting vascular injury monitoring. (2) Known allergies to chemotherapy drugs or severe reactions to chemotherapy side effects. (3) History of vascular stenosis, varicose veins, or thrombotic diseases. (4) Pregnant or breastfeeding women. (5) Patients who are lost to follow-up or do not complete all examinations during the study.

Sample size

This study uses a single-arm prognostic study design, expecting to detect the sensitivity and specificity of early vascular injury through vascular ultrasound examination. Based on preliminary small sample pilot data, the estimated incidence of vascular injury is 20%. To ensure the reliability of the study results, α is set to 0.05, β to 0.2 ($1-\beta=0.8$) and the sample size is calculated with an 80% detection rate. Through statistical calculation, it is estimated that at least 120 patients are needed to participate in the study. A total of 140 patients were included, with an expected sample loss rate of 10%.

Study indicators

Primary study indicators

Incidence of vascular injury: Vascular ultrasound examination is used to assess the occurrence of vascular injury at different time points (1 week, 1 month, and 3 months after chemotherapy), including vascular wall thickening, changes in vascular diameter and thrombosis.

Assessment of vascular injury severity: Vascular ultrasound is used to quantify the assessment of vascular wall thickness (intima-media thickness, IMT), vascular diameter and blood flow velocity, combined with clinical symptom assessment (such as phlebitis, local swelling, pain, etc.) to grade the severity of vascular injury.

Secondary study indicators

Clinical symptoms related to venous injury: Including local phlebitis, redness, swelling, pain, and local ulcers.

Clinical efficacy assessment: The relationship between chemotherapy efficacy and patient venous injury, analyzing the potential association between vascular injury and chemotherapy effects.

Laboratory parameters: White blood cell count, C-reactive protein (CRP) levels, and D-dimer levels were measured to assess inflammation and thrombosis risk.

Research methods

Vascular ultrasound examination

All study subjects underwent vascular ultrasound examination before the start of chemotherapy and at 1 week, 1 month, and 3 months after each chemotherapy session. GE LOGIQ E9 high-end color Doppler ultrasound equipment was used with a 7-12 MHz linear transducer to scan the patient's veins. The specific vessels examined included the forearm veins used for peripheral chemotherapy and the carotid arteries for IMT measurements. Vascular ultrasound examinations were conducted by experienced ultrasound physicians, and all imaging materials were reviewed by two independent ultrasound physicians to ensure the accuracy of the results.

Clinical assessment

Clinical symptom assessment, including grading of patient venous inflammation, redness, swelling and pain (mild, moderate, severe), was conducted simultaneously with each vascular ultrasound examination. Complications such as thrombosis and ulcer occurrence were also recorded.

Laboratory tests

Blood tests, including white blood cell count, C-reactive protein (CRP) levels and D-dimer, were performed on each patient before and 1 month and 3 months after chemotherapy. The level of D-dimer was used as an indicator of thrombosis to further assess the impact of chemotherapy drugs on blood vessels.

Chemotherapy cycle alignment

The time points for vascular ultrasound assessments (1 week, 1 month and 3 months) were aligned with the completion of each chemotherapy cycle. This approach ensures that the timing of ultrasound assessments corresponds to the cumulative exposure to chemotherapy drugs.

Table 1: Baseline Characteristics

Variable	Total (N=140)	Male (N=65)	Female (N=75)	P-value
Age (years)	56.3 ± 10.2	55.7 ± 10.3	56.8 ± 10.1	0.442
Chemotherapy cycles	5.2 ± 2.4	5.3 ± 2.6	5.1 ± 2.2	0.575
Comorbidities (N, %)				0.897
Hypertension	42 (30%)	21 (32%)	21 (28%)	
Diabetes	28 (20%)	12 (18%)	16 (21%)	
Tumor type				0.307
Breast cancer	40 (28.6%)	20 (30.8%)	20 (26.7%)	
Non-breast cancer	100 (71.4%)	45 (69.2%)	55 (73.3%)	

Table 2: Analysis of Vascular Injury Incidence

Time After Chemotherapy	Total Incidence (%)	Thrombosis (%)	Vascular Wall Thickening (%)	Abnormal Blood Flow (%)	χ^2	P-value
1 week	12.9% (18/140)	3.6% (5/140)	6.4% (9/140)	3.6% (5/140)	10.32	0.033
1 month	25.0% (35/140)	7.1% (10/140)	12.1% (17/140)	5.7% (8/140)	12.95	0.014
3 months	34.3% (48/140)	8.6% (12/140)	16.4% (23/140)	9.3% (13/140)	16.34	0.002

Table 3: Changes in Vascular Wall Thickness and Diameter

Timepoint	IMT (mm)	Vascular Diameter Change (mm)	t-value	P-value
Baseline (N=140)	0.61 ± 0.11	2.34 ± 0.22		
1 week (N=140)	0.62 ± 0.13	2.36 ± 0.24	1.44	0.115
1 month (N=140)	0.74 ± 0.18	2.45 ± 0.28	4.32	<0.01
3 months (N=140)	0.85 ± 0.22	2.55 ± 0.33	6.29	<0.01

Table 4: Distribution of Phlebitis Symptoms

Symptom Type	1 Week (N=140)	1 Month (N=140)	3 Months (N=140)	χ^2	P-value
Asymptomatic	121 (86.4%)	105 (75%)	90 (64.3%)	16.42	<0.01
Mild phlebitis	10 (7.1%)	16 (11.4%)	20 (14.3%)		
Moderate phlebitis	5 (3.6%)	8 (5.7%)	12 (8.6%)		
Severe phlebitis	4 (2.9%)	6 (4.3%)	10 (7.1%)		

Venous access device information

The type of venous access device used was recorded for each patient. Of the 140 patients, 60% used peripheral IV lines, 30% used PICC lines and 10% had implantable ports. The impact of different venous access devices on phlebitis and thrombosis risk was analyzed and discussed.

STATISTICAL ANALYSIS

Data analysis for this study was conducted using SPSS 26.0 statistical software. All quantitative data are expressed as mean ± standard deviation ($\bar{x}\pm s$) and count data are expressed as frequency and percentage. Independent sample t-tests or analysis of variance (ANOVA) were used for inter group comparisons. Chi-square tests were used to assess the correlation between the degree of vascular injury and clinical symptoms. Multiple regression analysis was used to assess the independent correlation between vascular ultrasound indicators and the incidence of venous injury. A P-value <0.05 was considered statistically significant.

RESULTS

Baseline Characteristics Analysis

Table 1 shows the baseline characteristics of the study subjects. In the overall sample, 46.4% were male patients and 53.6% were female patients. There were no significant differences in age, number of chemotherapy sessions, and distribution of underlying diseases (such as hypertension, diabetes) between the two groups (P-values all greater than 0.05), indicating that the basic conditions of the two groups were similar at baseline, making them suitable for comparative analysis.

Changes in vascular injury incidence over time

According to table 2 and fig. 1, the incidence of vascular injury gradually increased with the extension of chemotherapy time. One week after chemotherapy, the incidence of vascular injury was 12.9% (18/140), with thrombosis at 3.6% (5/140), vascular wall thickening at 6.4% (9/140), and abnormal blood flow at 3.6% (5/140). At one month, the total incidence of vascular injury increased to 25.0% (35/140), with the incidence of thrombosis,

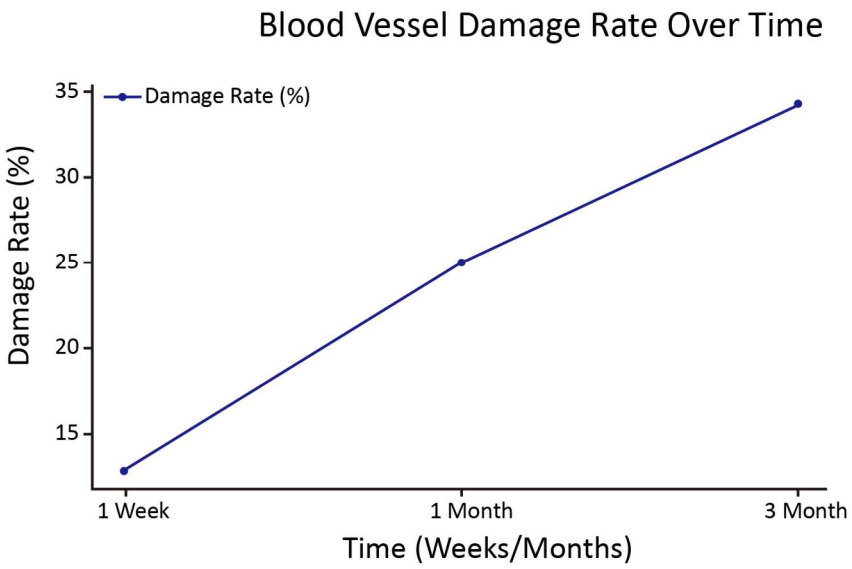

Fig. 1: Blood vessel damage rate over time

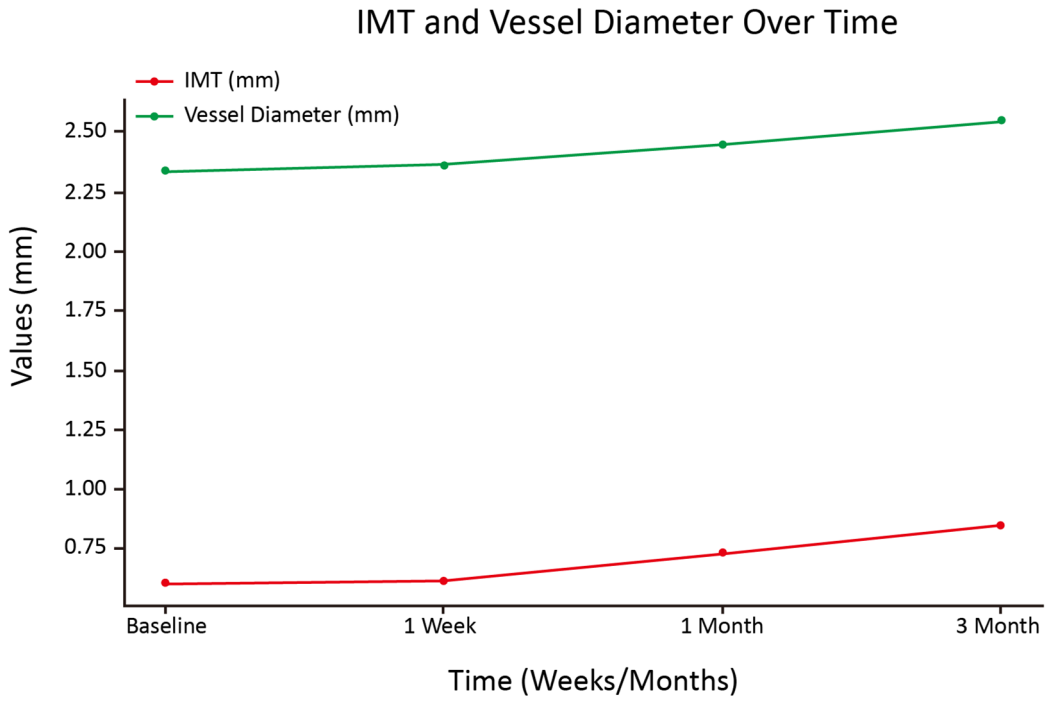

Fig. 2: IMT and vessel diameter over time

vascular wall thickening, and abnormal blood flow being 7.1% (10/140), 12.1% (17/140), and 5.7% (8/140), respectively. By three months, the total incidence was 34.3% (48/140), with thrombosis, vascular wall thickening, and abnormal blood flow at 8.6% (12/140), 16.4% (23/140) and 9.3% (13/140), respectively. Statistical analysis showed a significant upward trend in the incidence of vascular injury with the extension of chemotherapy time ($P<0.05$).

Changes in vascular wall thickness and diameter

Table 3 and fig. 2 show the changes in vascular wall thickness (IMT) and vascular diameter during chemotherapy. At baseline, the vascular wall thickness (IMT) was 0.61±0.11mm and the vascular diameter was 2.34±0.22mm. One week later, IMT slightly increased to 0.62±0.13mm, with little change in vascular diameter (2.36±0.24mm). At one month, IMT increased to 0.74±0.18mm, and vascular diameter was 2.45±0.28mm, and this change was statistically significant ($P<0.01$). At

three months, IMT further increased to 0.85±0.22mm, and vascular diameter was 2.55±0.33mm, and the differences compared to baseline values were still significant (P<0.01).

Changes in venous inflammation symptoms

Table 4 shows the changes in venous inflammation symptoms over chemotherapy time. One week after chemotherapy, 86.4% of patients were asymptomatic, 7.1% had mild phlebitis, 3.6% had moderate phlebitis, and 2.9% had severe phlebitis. At one month, asymptomatic patients decreased to 75%, mild venous inflammation patients increased to 11.4% and the incidence of moderate and severe venous inflammation was 5.7% and 4.3%, respectively. By three months, asymptomatic patients decreased to 64.3%, and mild, moderate, and severe venous inflammation patients were 14.3%, 8.6%, and 7.1%, respectively. These changes indicate that as chemotherapy time extends, venous inflammation symptoms gradually increase and the differences are statistically significant (P<0.01).

DISCUSSION

This study systematically analyzed the impact of chemotherapy on the vascular wall through dynamic observation of vascular injury during chemotherapy (Anastasiou *et al*., 2023; Mclaughlin *et al*., 2021), particularly the changes in vascular wall thickness, vascular diameter, thrombosis, and blood flow abnormalities at different time points (1 week, 1 month, and 3 months). Our results indicate that the incidence of vascular injury gradually increases with the extension of chemotherapy, especially with significant changes in vascular wall thickness and diameter, reflecting the long-term effects of chemotherapy on blood vessels. These findings provide valuable references for clinical practice, revealing the potential risks of chemotherapy-induced vascular injury, which is of significant clinical importance.

Firstly, regarding the baseline characteristics, the study included male and female patients with similar ages and chemotherapy sessions, and the distribution of various underlying diseases (such as hypertension and diabetes) showed no significant differences, ensuring the balance of the study subjects and providing an effective control for further analysis of the impact of chemotherapy on vascular injury (Lopez-Garzon *et al*., 2022; Stephenson *et al*., 2024). As shown in table 1, there were no statistically significant differences in age, chemotherapy sessions, and other aspects between males and females (P>0.05), which means that the influence of gender on vascular injury can be neglected in subsequent analyses, ensuring the reliability of the study results.

In the analysis of the incidence of vascular injury (table 2), we observed a gradually increasing trend in vascular injury after chemotherapy, and the incidence of thrombosis, vascular wall thickening, and blood flow abnormalities increased over time. This result is statistically significant (P<0.05), especially at 1 month and 3 months, where the incidence of vascular injury was higher than at 1 week. This may be related to the direct toxic effects of chemotherapy on vascular endothelial cells and the chronic inflammatory response induced by chemotherapy. Chemotherapy drugs cause injury to vascular endothelial cells and endothelial dysfunction, inducing changes in the thickness of the vascular wall and the formation of thrombosis (Terwoord *et al*., 2022). This injury may increase the risk of cardiovascular and cerebrovascular events in patients, so it is of great clinical significance to strengthen the monitoring and prevention of vascular injury during chemotherapy (Dent *et al*., 2020).

In the analysis of changes in vascular wall thickness (IMT) and vascular diameter (table 3), we found that the vascular wall thickness showed a gradually increasing trend with the progress of chemotherapy, and this change was particularly significant at 1 month and 3 months (P<0.01). During chemotherapy, the thickening of the vascular wall may be caused by vascular endothelial injury, changes in hemodynamics, and local inflammatory responses. The increase in vascular wall thickness indicates pathological changes in the patient's blood vessels, which may provide favorable conditions for thrombosis, further leading to changes in vascular diameter. The data in table 3 also reflect the trend of changes in vascular wall and vascular diameter after chemotherapy, consistent with the increase in the incidence of vascular injury, suggesting that the damage to blood vessels is not only short-term but long-term, posing a continuous threat to the patient's vascular health (Kumar & Vellapandian, 2024; Angjelova *et al*., 2024).

The distribution analysis of venous inflammation symptoms (table 4) also reveals the trend of changes in venous inflammation after chemotherapy. The data show that as the duration of chemotherapy extends, the proportion of asymptomatic patients gradually decreases, and the proportion of patients with mild, moderate, and severe phlebitis gradually increases, further confirming the aggravation of vascular injury and inflammatory response during chemotherapy. Especially at 1 month and 3 months, the incidence of mild to severe phlebitis significantly increased (P<0.01), which may be closely related to the occurrence of vascular wall thickening, thrombosis, and blood flow abnormalities. The exacerbation of venous inflammation may be related to the toxic effects of chemotherapy drugs and chronic inflammatory responses, indicating that clinical practice should strengthen the monitoring of venous inflammation symptoms in chemotherapy patients and take timely intervention measures to reduce further deterioration of vascular injury (Saketkoo *et al*., 2021).

The findings of this study are consistent with some conclusions in the existing literature. Studies have shown that the injury to vascular endothelium by chemotherapy drugs is a common phenomenon, especially for anticancer chemotherapy drugs such as paclitaxel and cisplatin, which cause injury to vascular endothelial cells through different mechanisms, thereby affecting the structure and function of blood vessels. Our study further proves that changes in vascular wall thickness and vascular diameter are key indicators of chemotherapy-induced vascular injury, and these changes are time-dependent, providing an important monitoring indicator for clinical practice, suggesting the need for regular vascular health assessment during chemotherapy.

However, this study also has certain limitations. Firstly, the study was conducted in a single center with a relatively small sample size, and the study subjects were mainly breast cancer and non-breast cancer patients, which may have certain biases. Secondly, the study mainly focused on the dynamic changes of vascular injury during chemotherapy but did not delve into the specific effects of specific chemotherapy drugs and different drug regimens on vascular injury. Therefore, future studies should expand the sample size, include patients with different types of cancer, and combine specific drug regimens to explore the impact of different chemotherapy drugs on blood vessels.

Future research can consider the following directions: firstly, by adding different types of vascular imaging methods, such as vascular ultrasound, CT angiography, etc., to more accurately assess the impact of chemotherapy on blood vessels. Secondly, it can combine early markers of vascular injury, such as serum endothelial cell injury markers, to further explore early prediction models for vascular injury. In addition, research can explore the application of vascular protective drugs during chemotherapy, such as the use of antioxidants or anti-inflammatory drugs, to reduce chemotherapy-induced vascular injury.

CONCLUSION

In summary, this study systematically analyzed vascular injury during chemotherapy and found that vascular injury gradually worsened with the extension of chemotherapy, especially with a significant increase in the incidence of vascular wall thickening and blood flow abnormalities. Our research provides a new perspective for clinical monitoring of vascular injury, suggesting that chemotherapy patients should undergo regular vascular health assessment and take corresponding intervention measures when necessary.

Institutional review board statement

This study was conducted in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent statement

Informed consent was obtained from all individual participants included in the study

Conflict-of-interest statement

The authors declare that they have no conflict of interest

REFERENCES

Anastasiou M, Oikonomou E, Theofilis P and Kaski JC (2023). Prolonged impact of anti-cancer therapy on endothelial function and arterial stiffness in breast cancer patients. *Vasc Pharmacol.,* **152**: 107195.

Angjelova A, Jovanova E, Polizzi A and Pavlovic A (2024). Impact of periodontitis on endothelial risk dysfunction and oxidative stress improvement in patients with cardiovascular disease. *J Clin Med.,* **13**(13):3781.

Aryal S, Park S, Park H, Kim J and Lee K (2023). Clinical trials for oral, inhaled and intravenous drug delivery systems for lung cancer and emerging nanomedicine-based approaches. *Int J Nanomedicine.,* **18**: 7865-7888.

Dent SF, Kikuchi R, Kondapalli L and Dent R (2020). Optimizing cardiovascular health in patients with cancer: A practical review of risk assessment, monitoring, and prevention of cancer treatment-related cardiovascular toxicity. *Am Soc Clin Oncol Educ Book.* **40**: 501-515.

Gao C, Xu D and Sun C (2021). Application of musculoskeletal ultrasound in real-time dynamic detection of Luschka joint hyperplasia of cervical vertebrae. *J Med Imaging Health Inform.,* **11**(2): 321-331.

Khanna AK and Khanna D (2023). Extravasation ulcers following chemotherapy. *In*: Khanna AK, ed. Uncommon ulcers of the extremities. Singapore: Springer Nature Singapore; pp.363-376.

Kumar V and Vellapandian C (2024). Unraveling the nexus between ambient air pollutants and cardiovascular morbidity: Mechanistic insights and therapeutic horizons. *Cureus.,* **16**(9): e68650.

Lopez-Garzon M, Cantarero-Villanueva I, Legeren-Alvarez M and Fernandez-Lopez C (2022). Prevention of chemotherapy-induced peripheral neuropathy with PRESIONA, a therapeutic exercise and blood flow restriction program: A randomized controlled study protocol. *Phys Ther.,* **102**(3): pzab282.

Lustberg MB, Kuderer NM, Desai A, Lyman GH, Kushi LH (2023). Mitigating long-term and delayed adverse events associated with cancer treatment: Implications for survivorship. *Nat Rev Clin Oncol.,* **20**(8): 527-542.

McLaughlin M, Florida-James G and Ross M (2021). Breast cancer chemotherapy vascular toxicity: A review of mediating mechanisms and exercise as a potential therapeutic. *Vasc Biol.,* **3**(1): R106-R120.

Qu X, Zhou D, Lu J, Wang Y and Li Z (2023). Cancer

nanomedicine in preoperative therapeutics: nanotechnology-enabled neoadjuvant chemotherapy, radiotherapy, immunotherapy and phototherapy. *Bioact Mater.,* **24**: 136-152.

Saketkoo LA, Frech T, Varju C and Csikos G (2021). A comprehensive framework for navigating patient care in systemic sclerosis: A global response to the need for improving the practice of diagnostic and preventive strategies in SSc. *Best Pract. Res. Clin. Rheumatol.,* **35**(3): 101707.

Stephenson E, McLaughlin M, Bray JW and Ross M (2024). Nutrition modulation of cardiotoxicity in breast cancer: A scoping review. *Nutrients.,* **16**(21): 3777.

Terwoord JD, Beyer AM and Gutterman DD (2022). Endothelial dysfunction as a complication of anti-cancer therapy. *Pharmacol Ther.,* **237**: 108116.

Tiwari A, Elgrably B, Saar G and Bhatia R (2022). Multi-scale imaging of vascular pathologies in cardiovascular disease. *Front Med.,* **8**: 754369.

Wei G, Wang Y, Yang G, Li H and Zhang J (2021). Recent progress in nanomedicine for enhanced cancer chemotherapy. *Theranostics.,* **11**(13):6370-6391.

Wong ND, Budoff MJ, Ferdinand K and Blaha MJ (2022). Atherosclerotic cardiovascular disease risk assessment: An American Society for Preventive Cardiology clinical practice statement. *Am. J. Prev. Cardiol.,* **10**: 100335.

Xu Y, Qi Y, Lu Z, Zhang L and Wang H (2024). Navigating precision: the crucial role of next-generation sequencing recurrence-risk assessment in tailoring adjuvant therapy for hormone receptor-positive, human epidermal growth factor receptor 2-negative early breast cancer. *Cancer Biol Ther.,* **25**(1): 2405060.

Yang Y, Zhang X, Zhang R, Li H and Wang X (2024). Current status and progress in arterial stiffness evaluation: A comprehensive review. *Adv. Ultrasound Diagn. Ther.,* **8**(4): 172-182.

Zeng ZM, Mo N, Zeng J, Li H and Wang X (2022). Advances in postoperative adjuvant therapy for primary liver cancer. *World J Gastrointest Oncol.,* **14**(9): 1604-1612.

Zhang T, Liu N, Xu J, Wang Y and Li H (2023). Flexible electronics for cardiovascular healthcare monitoring. *Innovation.,* **4**(5): 100458.