

Body action impacts the stability of nanomedicine tools in the drug delivery

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Abstract. Muscle strength and hypertrophy are equivalent when low-intensity resistance exercise is paired with blood flow restriction. This paper deals with the impact of physical exercise in the form of body activities on drug delivery using nanodevices. The body's actions impact the blood flow since the nano drug delivery devices are released into the bloodstream, and physical exercise and all the activities that change the blood flow influence the stability of these nanodevices. The nanodevice for the drug delivery purpose is modeled via nonuniform tube structures based on the high-order beam theory along with the nonlocal strain gradient theory. The nanodevice is made by a central nanomotor as well as the nanoblade in the form of truncated conical nanotubes carrying the nanomedicine. The mathematical simulation of rotating nanodevices is numerically solved, and the effect of various parameters on the stability of nanodevices has been studied in detail after the validation study.

Keywords: body activities; drug delivery; physical exercise; rotating nanostructures; stability analysis

1. Introduction

Using nanomaterials has caused significant improvement in disease treatment as well as diagnosis. Nanomedicines were developed to address numerous drug delivery challenges. Drug delivery (DD) is defined as a process in which a pharmaceutical substance would transport inside the body to cause a specific therapeutic effect. The development of drug delivery systems mostly focused on therapeutic effectiveness by using targeted delivery (Adepu and Ramakrishna 2021, Vargason *et al.* 2021). This is one of the main reasons that many scientists are attracted to nanomedicines despite their challenges such as intracellular delivery requirements, viability, stability, and expansion for live cells (Mahmoudi 2021). In the field of nanomedicine, engineered materials with a size range of 100 nm or less are used to enhance human health (Mitchell *et al.* 2021). Because of the remarkable impact of these nanomedicines on therapy, especially cancer therapy (Rommasi and Esfandiari 2021), it is vital to study the parameters that could affect the drug delivery process of these materials (de Lázaro and Mooney 2021).

Drug delivery systems have been enhanced with the help of manufacturing techniques and Nanotechnology advances. There are various studies about these systems (Maina *et al.* 2021, Pavlichenko *et al.* 2021, Tang *et al.* 2021). Different practical drug delivery systems like lipid-based, polymer-based, and conjugate-based systems were compared in detail for the RNA therapy field (Paunovska *et al.* 2022). Herrmann *et al.* (2021) insisted on the significance of extracellular vesicles as drug carriers. They even suggested efficient design steps of large-scale manufacturing

manufacturing for these carriers. Using precision medicine can help many patients diagnosed with cancer, which makes one of the recent developments in this field reasonable. It would be impossible to use these medicines unless we set some strategies which could make targeted drug delivery possible (Manzari *et al.* 2021). Having high loading capabilities made metal-organic frameworks (MOFs) attract much attention. This was one of the most important reasons that Lawson *et al.* (2021) decided to publish their research with a concentration on designing these frameworks for drug delivery. Transdermal drug delivery systems do not have the discomfort of using the common drug delivery systems with oral or parenteral delivery routes. This is the motivation for developing microneedle technology that can even perform drug monitoring after injecting the drug into the body (Alimardani *et al.* 2021, Sully *et al.* 2021, Ramadon *et al.* 2022). Cai *et al.* (2021) published a review study on the design of therapeutic drug carriers. The duty of these carriers is not just a simple delivery at a target tissue, they are also designed to be a therapeutic system by themselves. Any kind of physical activity could cause blood flow to increase and affect the therapy process since it would influence drug delivery. For example, this blood flow change was investigated in a study that evaluated fitness training influences on cerebrovascular blood flow by using MRI for measuring blood flow (Smith *et al.* 2021). This study reported that training has a heterogeneous impact on regional cerebral blood flow. Moreover, because blood flow increase in the body causes blood flow reduction in the kidneys, exercising is limited for the ones with reduced renal function, but Kawakami *et al.* (2022) proved that moderate-intensity continuous exercise cannot cause renal malfunction for these individuals. One of the main technologies that made using nanomedicines practical is nanomedicine equipment which should be able to do multiple smart tasks simultaneously. Furthermore, the development of nanomotors and nanodevices enhanced the drug delivery systems (Karsauliya *et al.* 2022, Varalakshmi

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et al. 2022). Díez *et al.* (2021) investigated ultrafast directional nanomotors and revealed their characteristics including rapid autonomous motion, stimuli-responsive controlled drug release, and versatility. There are numerous applications that micro/nanomotors that can be most useful. Drug transport, bio-imaging, cell isolation, cell stimulation, diagnostic, and monitoring are some examples that became possible because of these devices (Tezel *et al.* 2021). Having the capability to convert energy sources into mechanical forces, artificial nanomotors commonly known as active nanomotors have surpassed traditional nanomedicines (Chen *et al.* 2022). Micro-nano motors (MNMs) can use the surrounding environment and turn it into mechanical motion. MNMs with taxis behavior are an example of these nanomotors that are able to automatically find and move to the target location even in rheological conditions that imitate blood flow (Gao *et al.* 2022). The implementation of nanomotors for clinical applications as well as its challenges were investigated in real-world situations. It has been concluded that among all of the capabilities of these nanomachines the ability to self-moving and multi-tasking are the most helpful ones that could help surgeons and physicians (Rastmanesh *et al.* 2021). In similar research about nanorobots with intelligence, the mentioned characteristics of these systems were emphasized. They also pointed out that chemical reactions, applying external forces, and motile cells are the most common ways that nanorobots use to navigate their way in biological conditions (Giri *et al.* 2021, Singh *et al.* 2021, Gupta *et al.* 2022). Nanorobots are widely developed for tumor-targeting therapy. Huang *et al.* (2021a) focused on dynamic the control of nanomotors as well as the conceptual design of stimuli-responsive nanorobots. Nanosized drug carrier (NDC) could be used in acute kidney injury (AKI) cases which is another example of the application of nanomedicines. NDCs could be helpful for AKI since they are very effective in renal tissue targeting and reno-protective agents' improvement (Geot *et al.* 2022). Moreover, chronic diseases also attract self-regulated nano delivery systems that can detect the changes in physiological indices and alter their performance (Wang *et al.* 2021). During therapy procedures with nanomedicines, imaging techniques like MRI can provide information about the condition of these nanomedicines and their interaction with the biological environment to help the treatment monitoring (Ansari *et al.* 2021, Bernal *et al.* 2021, Bruno *et al.* 2022). An alternative method to eliminate the toxic effects of the fuels that power nanomachines is to use gold-nickel nanowires for drug delivery. There are various production challenges in the development of these nanowires. Karaca *et al.* (2021) represented their exclusive fabrication method which requires DC magnetron sputtering of nickel after preparing the gold part via electrochemical methods. The popularity of nano-structures in medical fields made scientists develop mathematical simulations for them. Classical theories generate inaccurate results. That's the reason that the continuum mechanics model is preferred for investigating the mechanical behavior of these structures (Kolitsi *et al.* 2022, Miller *et al.* 2022). Roudbari *et al.* (2022) gathered important continuum mechanics models related to nano-structures in their article. The mathematical models can play a vital role in the optimization of the shape,

type, and size of nanoparticles inside drug delivery systems. Malikan and Eremeyev (2021) published a review article that investigated different simulation tools for improving drug delivery systems on the basis of nanoparticles. A metaphysics modeling was developed to simulate thrombolysis by activated platelet-targeted nanomedicine. The results showed that this modeling could be useful for optimizing treatment regimens of thrombolytic therapies by performing a benefit/risk investigation (Gu *et al.* 2022).

Based on the authors' knowledge, investigating the effect of training and exercise on drug delivery systems that perform based on nanodevices would be a unique study topic (Li *et al.* 2021, Si *et al.* 2021, Zhang *et al.* 2021a, 2022a, b, Cao *et al.* 2022a, b, Wang *et al.* 2022a,). When humans involve in physical activities, the heart beats faster and tries to pump more blood to body cells since cellular metabolism increases in such conditions and cells need more oxygen which blood would provide for them. An increase in blood flow would affect the performance of nanodevices since they are released into the bloodstream to find their target location. Among all of the different characteristics of nanodevices, we focused on stability. Using high-order shear beam theory and the nonlocal strain gradient theory, we modeled a nanodevice with a non-uniform tube structure for the drug-delivery purpose. The nanodevice was constructed from a central nanomotor as well as two nanoblades. The nanoblades were truncated conical nanotubes in shape and their main job was to carry the medicine. A numerical solution was presented for the mathematical simulation of rotating nanodevices. In the results section, we discussed the influence of different parameters on the stability of nanodevices via our simulation. Fig. 1 illustrates the nanodevice with its nanomotor and two nanoblades.

2. Mathematical modeling

In this section, we have mathematically simulated the mechanical movements of small-scale nanodevices carrying the nanomedicine, and the impact of body activities in the form of the change in blood flow is investigated in detail. The internal blade radius is constant, and it is shown as ' Ri ', also, the external radius ' Re ' varies along the blade length according to the following equation:

$$Re = \bar{R}(1 - \tau x L^{-1}) \quad (1)$$

where ' τ ' is the rate of radius change. The high-order sinusoidal shear deformation beam theory is used for mathematical modeling of rotating nanostructures according to the following displacement fields, along the x -axis (u_x), y -axis (u_y), and z -axis (u_z).

$$\begin{aligned} u_x &= u(x, t) - z \frac{\partial w(x, t)}{\partial x} + \\ &\quad \frac{Re - Ri}{\pi} \sin\left(\frac{\pi z}{Re - Ri}\right) \frac{\partial w(x, t)}{\partial x} \\ &\quad + \frac{Re - Ri}{\pi} \sin\left(\frac{\pi z}{Re - Ri}\right) \psi(x, t) \\ u_y &= 0 \\ u_z &= w \end{aligned} \quad (2)$$

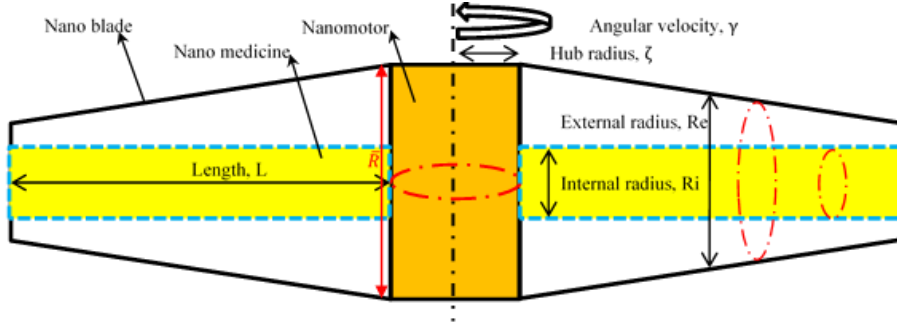


Fig. 1 Schematic of nanodevice carrying the nano-drug, involving the nanomotor and nanoblade

where ‘ ψ ’ is the rotation parameter, and ‘ u ’ and ‘ w ’ are the axial and lateral movements. The virtual potential energy (δP) based on the high-order beam theory is calculated as follows (Hashemi *et al.* 2019, Moayedi *et al.* 2019, 2020a, b, Oyarhossein *et al.* 2020, Shariati *et al.* 2020a):

$$\begin{aligned} \delta P = & 1/2 \iiint \sigma : \varepsilon dv = +G_{10} \mu_{,x} \Big|_0^L \delta(u) \\ & - \int_0^L \frac{\partial}{\partial x} (G_{10} \mu_{,x}) dx \delta(u) - \frac{\partial}{\partial x} (G_{21} w_{,xx}) \Big|_0^L \delta(w) \\ & + \int_0^L \frac{\partial^2}{\partial x^2} (G_{21} w_{,xx}) dx \delta(w) + G_{21} w_{,xx} \Big|_0^L \delta(w_{,x}) \\ & + \int_0^L \frac{\partial^2}{\partial x^2} (G_{23} w_{,xx}) dx \delta(w) + G_{23} w_{,xx} \Big|_0^L \delta(w_{,x}) \\ & - \frac{\partial}{\partial x} (G_{23} w_{,xx}) \Big|_0^L \delta(w) - \int_0^L \frac{\partial}{\partial x} (G_{23} w_{,xx}) dx \delta(\psi) \\ & - \int_0^L \frac{\partial}{\partial x} (G_{23} \psi_{,x}) dx \delta(\psi) - \frac{\partial}{\partial x} (G_{23} \psi_{,x}) \Big|_0^L \delta(w) \\ & + G_{23} \psi_{,x} \Big|_0^L \delta(\psi) + \int_0^L \frac{\partial^2}{\partial x^2} (G_{23} \psi_{,x}) dx \delta(w) \\ & + G_{23} \psi_{,x} \Big|_0^L \delta(\psi) + G_{23} \psi_{,x} \Big|_0^L \delta(w) + G_{20} w_{,xx} \Big|_0^L \delta(w_{,x}) \\ & - 2 \int_0^L \frac{\partial^2}{\partial x^2} (G_{22} w_{,xx}) dx \delta(w) - 2G_{22} w_{,xx} \Big|_0^L \delta(w_{,x}) \\ & + 2 \frac{\partial}{\partial x} (G_{22} w_{,xx}) \Big|_0^L \delta(w) - G_{22} w_{,xx} \Big|_0^L \delta(\psi) \\ & - \int_0^L \frac{\partial^2}{\partial x^2} (G_{22} \psi_{,x}) dx \delta(w) - G_{22} \psi_{,x} \Big|_0^L \delta(w_{,x}) \\ & + \int_0^L G_{20} w_{,xx} \delta(\psi) + G_{20} w_{,xx} \delta(\psi) dx + G_{20} \psi_{,x} \Big|_0^L \delta(w) \\ & + \frac{\partial}{\partial x} (G_{22} \psi_{,x}) \Big|_0^L \delta(w) - \int_0^L \frac{\partial}{\partial x} (G_{20} (\psi)) dx \delta(w) \\ & - \int_0^L \frac{\partial}{\partial x} (G_{20} w_{,xx}) dx \delta(w) + \int_0^L \frac{\partial}{\partial x} (G_{22} w_{,xx}) dx \delta(\psi) \end{aligned} \quad (3)$$

where

$$\delta K = \int \left\{ \begin{array}{l} m_{23} (\dot{w}_{,x} + \dot{\psi}) \delta(\dot{w}_{,x} + \dot{\psi}) \\ -m_{22} (\dot{w}_{,x} + \dot{\psi}) \delta(\dot{w}_{,x}) \\ -m_{22} \dot{w}_{,x} \delta(\dot{\psi}) + m_{21} (\dot{w}_{,x}) \delta(\dot{w}_{,x}) \\ +m_{10} \dot{u} \delta(\dot{u}) + m_{10} \dot{w} \delta(\dot{w}) \end{array} \right\} dx \quad (4)$$

In this equation, ‘ E ’ is the elasticity modulus, and ‘ K_s ’ is the shear correction factor (Jiao *et al.* 2021, Moradi *et al.* 2021, Zhao *et al.* 2021). According to the high-order sinusoidal shear deformation beam theory, the virtual Kinetic energy (δK) is calculated as follows (Hashemi *et al.* 2019, Al-Furjan *et al.* 2020c, Chahshmech *et al.* 2020, Lori *et al.* 2020, Najari *et al.* 2020, Shariati *et al.* 2020b):

$$\delta K = \int \left\{ \begin{array}{l} m_{23} (\dot{w}_{,x} + \dot{\psi}) \delta(\dot{w}_{,x} + \dot{\psi}) \\ -m_{22} (\dot{w}_{,x} + \dot{\psi}) \delta(\dot{w}_{,x}) \\ -m_{22} \dot{w}_{,x} \delta(\dot{\psi}) + m_{21} (\dot{w}_{,x}) \delta(\dot{w}_{,x}) \\ +m_{10} \dot{u} \delta(\dot{u}) + m_{10} \dot{w} \delta(\dot{w}) \end{array} \right\} dx \quad (5)$$

where

$$\begin{aligned} & \{m_{10} \quad m_{21} \quad m_{22} \quad m_{23}\}^T \\ & = \iint \left\{ \begin{array}{l} \rho \\ \rho r^2 \sin^2(\theta) \\ \rho r \sin(\theta) \frac{Re-Ri}{\pi} \sin\left(\frac{\pi r \sin(\theta)}{Re-Ri}\right) \\ \rho \left(\frac{Re-Ri}{\pi}\right)^2 \sin^2\left(\frac{\pi r \sin(\theta)}{Re-Ri}\right) \end{array} \right\} r dr d\theta \quad (6) \end{aligned}$$

In the above equation ‘ ρ ’ is the density. The bloodstream impact on the nanodevice movement and its external force is mathematically modeled via an external load. In this calculation, the virtual energy of the external loading due to the blood flow, as well as the centrifugal force of rotating, is defined as follows (Adamian *et al.* 2020, Al-Furjan *et al.* 2020a, b, Li *et al.* 2020, Zare *et al.* 2020, Dai *et al.* 2021b):

$$\begin{aligned} \delta V = & \int_V F^{BF} r dr d\theta dx \delta(w) + \\ & F^R w_{,x} \Big|_0^L \delta(w) - \int \partial/\partial x (F^B w_{,x}) dx \delta(w) \end{aligned} \quad (7)$$

where, ‘ F^{BF} ’ is the blood flow force, and is defined as follows (Liu *et al.* 2020b, Habibi *et al.* 2021, He *et al.* 2021, Huang *et al.* 2021b, Liu *et al.* 2021a, Zhang *et al.* 2021b):

$$F^{BF} = \bar{F} \times \chi \sin\left(\frac{n\pi}{L} x\right) \sin(\omega t) \quad (8)$$

In which, ‘ \bar{F} ’ is the dynamic external bending load, ‘ ω ’ is the external excitation frequency, and ‘ χ ’ is the length of

the beam under the loading. Also, ‘ F^R ’ is the centrifugal force due to the rotation and is calculated as follows (Liu *et al.* 2020a, Wang *et al.* 2020, Zhou *et al.* 2020, Dai *et al.* 2021a, Guo *et al.* 2021, Shao *et al.* 2021, Wu and Habibi 2021):

$$F^R = \int_A \int_x^L \rho \gamma^2 (\zeta + x) dA dx \quad (9)$$

Then based on the nonlocal strain gradient theory which is presented as the following equations (Huang *et al.* 2021d, Liu *et al.* 2021b, Ma *et al.* 2021, Yu *et al.* 2022):

$$[E : \varepsilon_{ij}](1 - l^2 \nabla^2) = [\sigma_{ij}](1 - (ea)^2 \nabla^2) \quad (10)$$

The general stress field includes both nonlocal elastic stress and strain gradient stress fields will be obtained (Shafiei and She 2018, Shafiei *et al.* 2019, 2020). In which, ‘ l ’ is the strain gradient parameter, ‘ ea ’ is the nonlocal parameter, and ‘ ∇ ’ is the Laplace operator. The Hamilton principle is used to link the generated virtual energy of potential work, Kinetic, and external work as the following equation (Ebrahimi and Shafiei 2017, Ghadiri *et al.* 2017e, Mirjavadi *et al.* 2017a, Shafiei and Kazemi 2017a, Shafiei *et al.* 2017d, Azimi *et al.* 2018):

$$\int_{t_1}^{t_2} \delta H dt = \int_{t_1}^{t_2} \delta P + \delta V - \delta K dt = 0 \quad (11)$$

The nonlocal partial differential (PD) governing equations will be obtained by applying the nonlocal strain gradient theory in the form of stress fields to the presented virtual energy using the Hamilton principle (Ebrahimi *et al.* 2017, Ghadiri *et al.* 2017c, d, Mirjavadi *et al.* 2017d, Shafiei and Kazemi 2017b, Shafiei *et al.* 2017c).

$$(1 - l^2 \partial^2 / \partial x^2) G_{10} \mu_{,xxx} = (1 - (ea)^2 \partial^2 / \partial x^2) m_{10} \ddot{u} \quad (12a)$$

$$\begin{aligned} &(1 - l^2 \partial^2 / \partial x^2) (G_{23} - G_{22}) \psi_{,xx} \\ &+ (l^2 \partial^2 / \partial x^2 - 1) G_{20} (\psi_{,x} + w_{,xx}) \\ &+ (1 - l^2 \partial^2 / \partial x^2) G_{22} w_{,xxx} \\ &(1 - (ea)^2 \partial^2 / \partial x^2) [(m_{23} - m_{22}) \dot{w}_{,x} + m_{3j} \ddot{w}] \end{aligned} \quad (12b)$$

$$\begin{aligned} &(1 - l^2 \partial^2 / \partial x^2) (G_{23} - G_{22}) (\psi_{,xxx} + w_{,xxxx}) \\ &- (1 - l^2 \partial^2 / \partial x^2) (G_{22} - G_{21}) w_{,xxxx} \\ &- (1 - l^2 \partial^2 / \partial x^2) G_{10} (w_{,xx} + \psi_{,x}) - \\ &(1 - (ea)^2 \partial^2 / \partial x^2) (F^R w_{,xx} + d/dx (F^R) w_{,x}) \\ &+ (1 - (ea)^2 \partial^2 / \partial x^2) F^{BF} = \\ &((ea)^2 \partial^2 / \partial x^2 - 1) (m_{10} \ddot{w}) \\ &+ (1 - (ea)^2 \partial^2 / \partial x^2) (m_{23} - m_{22}) \ddot{w}_{,x} + \\ &(1 - (ea)^2 \partial^2 / \partial x^2) (m_{23} + m_{21} - 2m_{22}) \ddot{w}_{,xx} \end{aligned} \quad (12c)$$

Boundary conditions are:

$$\delta(u): G_{10} \partial u / \partial x = 0 \quad (13a)$$

Table 1 Comparison of presented nonlocal dimensionless frequency ($\sqrt{\omega L^2 \sqrt{G_{10}/G_{21}}}$) of cantilever nanobeam with results of Lu *et al.* (2006b)

	Presented study	Lu <i>et al.</i> (2006b)
‘ea=0’	1.873460038	1.8751
‘ea=L/10’	1.877556452	1.8792
‘ea=2L/10’	1.890245344	1.8919
‘ea=3L/10’	1.913724791	1.9154
‘ea=4L/10’	1.952590769	1.9543
‘ea=5L/10’	2.020131646	2.0219

$$\begin{aligned} \delta(w_{,x}): &-(2G_{22} - G_{23} - G_{21}) w_{,xxx} \\ &+ (G_{23} - G_{22}) \psi_{,x} = 0 \end{aligned} \quad (13b)$$

$$\begin{aligned} \delta(w_{,x}): &-G_{23} \psi_{,xx} ((G_{23} - G_{22}) \psi_{,x}) \\ &+ G_{22} \psi_{,xx} / \partial x ((2G_{22} - G_{23} - G_{21}) w_{,xxx}) \\ &+ G_{22} (w_{,xx} + \psi_{,x}) + F^R w_{,x} = 0 \end{aligned} \quad (13c)$$

$$\delta(\psi): G_{23} (\psi_{,xx} + w_{,xxx}) - G_{22} w_{,xxx} = 0 \quad (13d)$$

Numerical solution procedure

This section provides the numerical method to solve the generated PD governing equations. The generalized differential quadrature approach and the Newmark procedure are employed to calculate the time-dependent and time-independent results. According to the modal analysis, which is the methodology to solve the eigenvalue problem, the natural frequency will be obtained based on the following assumptions (Ghadiri *et al.* 2017a, b, Mirjavadi *et al.* 2017b, c, Shafiei *et al.* 2017a, b):

$$\begin{aligned} u &= U e^{i\omega t} \\ \psi &= \Psi e^{i\omega t} \\ w &= W e^{i\omega t} \end{aligned} \quad (14)$$

where ‘ ω ’ is the natural frequency which is calculated as follows based on the generalized differential quadrature method (GDQM):

$$\omega^2 = \begin{bmatrix} K_{11} & 0 & 0 \\ 0 & K_{22} & K_{23} \\ 0 & K_{32} & K_{33} \end{bmatrix} \begin{bmatrix} M_{11} & 0 & 0 \\ 0 & M_{22} & M_{23} \\ 0 & M_{32} & M_{33} \end{bmatrix}^{-1} \begin{Bmatrix} U \\ \Psi \\ W \end{Bmatrix} \quad (15)$$

Here ‘ M ’ and ‘ K ’ are the mass and stiffness matrices which are defined as follows (Ebrahimi and Shafiei 2016, Shafiei *et al.* 2016c, d, f, Ebrahimi *et al.* 2017, Shivanian *et al.* 2017):

$$\begin{aligned} [K_{11}] &= (1 - l^2 \partial^2 / \partial x^2) \left[G_{10} \sum_{j=1}^n D_{ij}^{(2)} \right] \\ [M_{11}] &= m_{10} - (ea)^2 m_{10}'' - (ea)^2 m_{10} \sum_{j=1}^n D_{ij}^{(2)} \end{aligned} \quad (16a)$$

Table 2 The impact of angular velocity (γ) and the section change rate (τ) on the fundamental frequency (GHz) of cantilever nanoblade carrying the nanomedicine, $\bar{R}=10(\text{nm})$, $R_i=5(\text{nm})$, $L=200(\text{nm})$

	' $\tau = -0.4$ '	' $\tau = -0.2$ '	Uniform section	' $\tau = +0.2$ '	' $\tau = +0.4$ '
Non-rotating	1.0735393	1.1458222	1.2365982	1.3548777	1.5174639
' $\gamma L^2=1 \times \sqrt{(G_{21}/m_{10})}$ '	1.1381024	1.2073167	1.2948479	1.4096422	1.5683907
' $\gamma L^2=2 \times \sqrt{(G_{21}/m_{10})}$ '	1.3123574	1.3748531	1.4550977	1.5618425	1.7114445
' $\gamma L^2=3 \times \sqrt{(G_{21}/m_{10})}$ '	1.5587735	1.6145018	1.6871845	1.7852696	1.9245941
' $\gamma L^2=4 \times \sqrt{(G_{21}/m_{10})}$ '	1.847322	1.8976539	1.9641929	2.0550472	2.1854538
' $\gamma L^2=4 \times \sqrt{(G_{21}/m_{10})}$ '	2.1599122	2.2062412	2.2682054	2.3536013	2.4770932
' $\gamma L^2=6 \times \sqrt{(G_{21}/m_{10})}$ '	2.4864722	2.5298541	2.5884836	2.6699003	2.7882773
' $\gamma L^2=7 \times \sqrt{(G_{21}/m_{10})}$ '	2.8214055	2.8625738	2.918752	2.9972799	3.1119318
' $\gamma L^2=8 \times \sqrt{(G_{21}/m_{10})}$ '	3.1615326	3.200985	3.2553205	3.3317283	3.4436685
' $\gamma L^2=9 \times \sqrt{(G_{21}/m_{10})}$ '	3.5049937	3.5430699	3.5959797	3.6708032	3.7807555
' $\gamma L^2=10 \times \sqrt{(G_{21}/m_{10})}$ '	3.8506666	3.8876036	3.9393756	4.02993	4.1214698

$$[K_{22}] = (l^2 \partial^2 / \partial x^2 - 1) \left[G_{20} \sum_{j=1}^n D_{ij}^{(1)} \right] + D_{ij}^{(q)} = D_{ij}^{(1)} D_{ij}^{(q-1)} = D_{ij}^{(q-1)} (x_i - x_j)^{-1} \quad (17a)$$

$$(1 - l^2 \partial^2 / \partial x^2) \left[(G_{23} - G_{22}) \sum_{j=1}^n D_{ij}^{(2)} \right] \quad (16b)$$

$$[M_{22}] = \left(1 - (ea)^2 \frac{\partial^2}{\partial x^2} \right) \left[(m_{23} - m_{22}) \sum_{j=1}^n D_{ij}^{(1)} \right] \quad (17b)$$

$$[K_{23}] = -G_{20} + l^2 G_{20}'' + l^2 G_{20} \sum_{j=1}^n D_{ij}^{(2)} \quad X(x_i) = \prod_{j=1, j \neq i}^n (x_i - x_j) \quad (17c)$$

$$+ G_{23} \sum_{j=1}^n D_{ij}^{(2)} - l^2 G_{23}'' \sum_{j=1}^n D_{ij}^{(2)} - l^2 G_{23} \sum_{j=1}^n D_{ij}^{(4)} \quad (16c)$$

$$[M_{23}] = m_3 - (ea)^2 \left[m_3'' + m_3 \sum_{j=1}^n D_{ij}^{(2)} \right]$$

$$[K_{32}] = -(1 - l^2 \partial^2 / \partial x^2) \left[G_{10} \sum_{j=1}^n D_{ij}^{(1)} \right] +$$

$$(1 - l^2 \partial^2 / \partial x^2) \left[(G_{23} - G_{22}) \sum_{j=1}^n D_{ij}^{(2)} \right] \quad (16d)$$

$$[M_{32}] = \left(1 - (ea)^2 \frac{\partial^2}{\partial x^2} \right) \left[(m_{23} - m_{22}) \sum_{j=1}^n D_{ij}^{(1)} \right]$$

$$[K_{33}] = (1 - l^2 \partial^2 / \partial x^2) \left[(G_{23} + G_{21} - 2G_{22}) \sum_{j=1}^n D_{ij}^{(4)} \right] -$$

$$(1 - l^2 \partial^2 / \partial x^2) \left[G_{10} \sum_{j=1}^n D_{ij}^{(2)} \right] + (1 - (ea)^2 \frac{\partial^2}{\partial x^2}) F^{BF}$$

$$(1 - (ea)^2 \frac{\partial^2}{\partial x^2}) \left[F^R \sum_{j=1}^n D_{ij}^{(2)} + d/dx (F^R) \sum_{j=1}^n D_{ij}^{(1)} \right] \quad (16e)$$

$$[M_{33}] = (ea)^2 \left[m_{10}'' + m_{10} \sum_{j=1}^n D_{ij}^{(2)} \right] - m_{10}$$

$$+ (1 - (ea)^2 \frac{\partial^2}{\partial x^2}) \left[(m_{23} + m_{21} - 2m_{22}) \sum_{j=1}^n D_{ij}^{(2)} \right]$$

where ' $\sum D^{(q)}$ ' is q^{th} order weighting coefficient and is defined as follows (Azimi *et al.* 2016, Ghadiri and Shafiei 2016a, c, Shafiei *et al.* 2016a, e, g):

In which

$$D_{ij}^{(q)} = X(x_i) X^{-1}(x_j) (x_i - x_j)^{-1} \quad (17b)$$

Here

$$X(x_i) = \prod_{j=1, j \neq i}^n (x_i - x_j) \quad (17c)$$

It is noted that the grid points are defined according to the Chebyshev-Gauss-Lobatto as follows (Ghadiri *et al.* 2016a, b, c, d, Ghadiri and Shafiei 2016b, Shafiei *et al.* 2016b):

$$x_i = 0.5L \left(1 - \cos \left((i-1) \pi (N-1)^{-1} \right) \right) \quad (17d)$$

So, the time-independent results (natural frequency) were generated based on the GDQM, lastly, the time-dependent results in response to the external harmonic load of the bloodstream are calculated via Newmark beta approach (Hou *et al.* 2021, Huang *et al.* 2021c, Xu *et al.* 2021, Wang *et al.* 2022b).

4. Results and discussion

As mentioned in the previously published reports, the exercise improves the blood flow velocity (Globus *et al.* 1983, Hellström and Wahlgren 1993, van der Kleij *et al.* 2018). This section investigates the impact of exercise in the form of external force for different parameters. According to Eq. (8), improving the blood flow velocity enhances the external excitation frequency (ω). Here, the impact of this parameter on the time-dependent dynamic deflection of nanodevice is analyzed in detail. It is noted that improving the external excitation frequency means the blood flow increases. Before discussing the results, the validation of the presented results was carried out. The

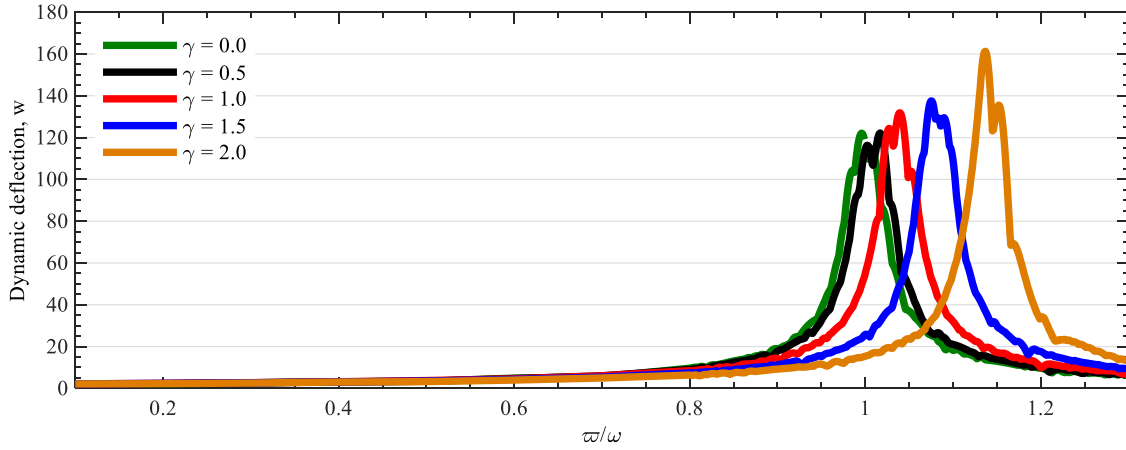


Fig. 2 Effect of rotation speed ($\gamma \times 351.6e6$) on the resonant frequency ($\bar{\omega} = \omega$) and dynamic deflection ($w \times 100G_{21}/L^4\bar{F}$) of nanodevices carrying the nano-drug versus the external excitation frequency ($\bar{\omega}$) due to the body action, $\bar{R}=10(\text{nm})$, $R_i=5(\text{nm})$, $L=200(\text{nm})$, $\tau=0.3$

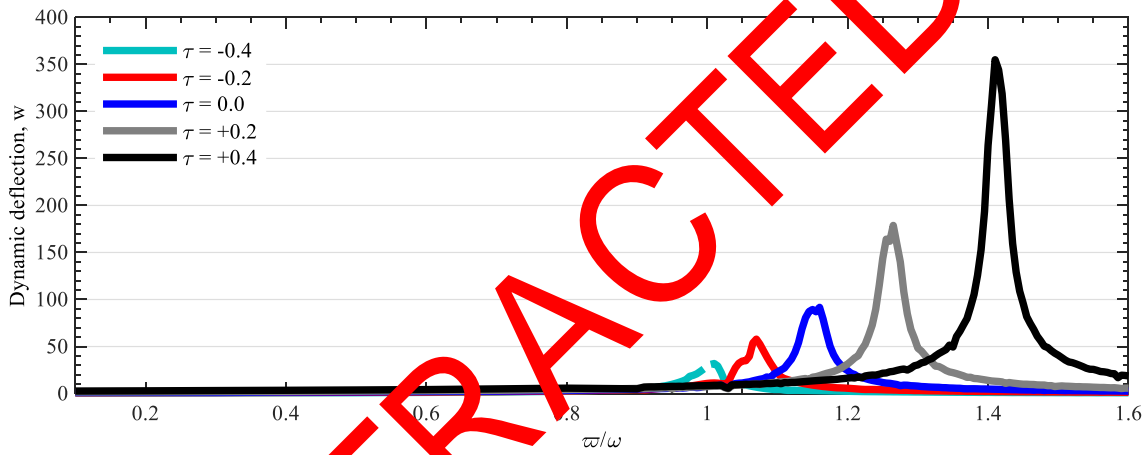


Fig. 3 Influence of cross-section change rate (τ) on the resonant frequency ($\bar{\omega} = \omega$) and dynamic deflection ($w \times 100G_{21}/L^4\bar{F}$) of nanoblade taking the nano-drug versus the external excitation frequency ($\bar{\omega}$) due to the physical exercise, $\bar{R}=10(\text{nm})$, $R_i=5(\text{nm})$, $L=200(\text{nm})$, $\gamma=35.16e6$

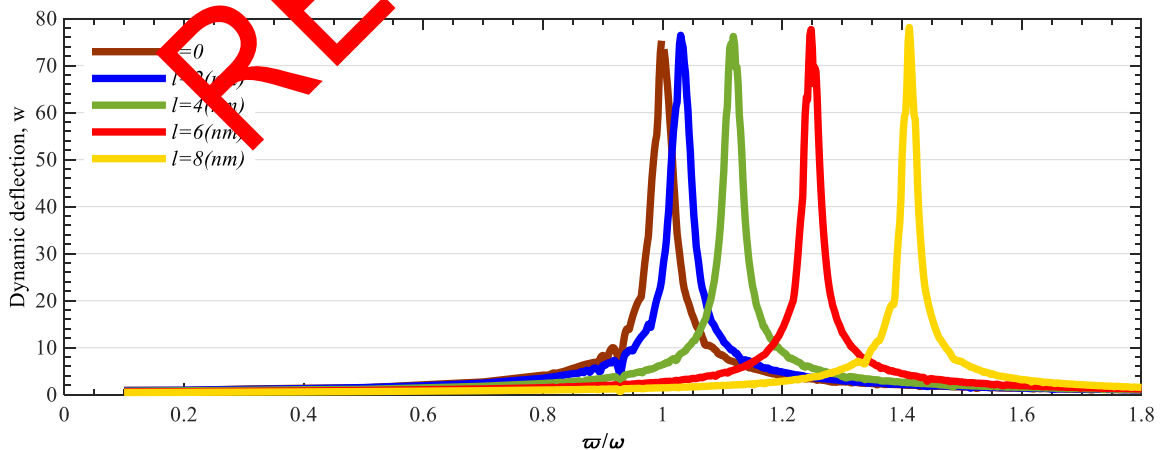


Fig. 4 Influence of strain gradient parameter (l) on the resonant frequency ($\bar{\omega} = \omega$) and dynamic deflection ($w \times 100G_{21}/L^4\bar{F}$) of nanoblade carrying the nano-medicine for different external excitation frequency ($\bar{\omega}$) values due to the physical exercise, $\bar{R}=10(\text{nm})$, $R_i=5(\text{nm})$, $L=200(\text{nm})$, $\tau=-0.1$, $\gamma=35.16e6$

mechanical properties of the nanodevices made of Ni-Ag are listed as follows (Gao and Wang 2014):

Elasticity modulus (E)=83 (GPa), Density (ρ)= 10.49 (g/cc).

Table 3 Influence of small-scale parameters involving nonlocal (ea) and strain gradient (l) parameters on the fundamental frequency (MHz) of rotating truncated conical cylindrical nanoblade carrying the nano-drug, $\tau=0.3$, $\gamma=2.5 \times \sqrt{(G_{21}/m_{10})/L^2}$, $\bar{R}=10(\text{nm})$, $R_i=5(\text{nm})$, $L=200(\text{nm})$

	'l=0×L'	'l=0.2×L'	'l=0.3×L'	'l=0.4×L'
'ea=1.0×L'	2.0697803	6.2132678	9.4425739	14.056185
'ea=1.1×L'	1.996538	5.5825919	8.5540865	12.77835
'ea=1.2×L'	1.9371937	5.0391251	7.8003577	11.713488
'ea=1.3×L'	1.8880938	4.5626039	7.1519562	10.81245
'ea=1.4×L'	1.8468557	4.1376977	6.5871528	10.040132
'ea=1.5×L'	1.8118268	3.7523492	6.0895908	9.3707903
'ea=1.6×L'	1.7818044	3.3965636	5.6467281	8.7851159
'ea=1.7×L'	1.7558811	3.0613994	5.2487759	8.2683443
'ea=1.8×L'	1.7333537	2.7378904	4.8879619	7.8089919
'ea=1.9×L'	1.7136662	2.415429	4.5580061	7.3979923
'ea=2.0×L'	1.6963723	2.0782953	4.2537058	7.0280927

To validate our results we decided to compare nonlocal dimensionless frequency values that were calculated in this study with the results of Lu *et al.* (2006a). The comparison was carried out with different nonlocal parameters. Table 1 presents the validation study's results for cantilever nanobeam. As the nonlocal parameter increases, the nonlocal dimensionless frequency also grows while there is a small difference between the obtained results and the reference values. Considering the reference values as accurate results, we have achieved approximately 0.087% error in our results, which is a significant achievement.

Table 2 presents the influence of two different parameters on the fundamental frequency of the cantilever nanoblade carrying the nanomedicine by changing the angular velocity and the section change rate. We gained the presented results. The angular velocity rises by increasing the coefficient of its equation in ten steps and the impact of the section change rate is investigated with 5 different values. The growth of both parameters causes an escalation in the fundamental frequency value. Changes in the angular velocity have a lesser impact than changes in the section change rate in this table. The column-wise growth of fundamental frequency is about 10.8% on average while row-wise growth is about 4.1% on average.

Fig. 2 depicts the influence of rotation speed on the dynamic deflection in both resonant and external excitation situations. Each plot starts with an almost zero amount of dynamic deflection and then peaks at a specific excitation frequency and finally decreases to a small value of dynamic deflection. At the point that we have the resonant frequency, we can investigate the impact of rotation speed without having any external excitation. In this situation, the results show that we can have the maximum dynamic deflection when the rotation speed is equal to zero and this value would decline as we use a higher rotation speed until the deflection would fall from almost 120 to 20. Increasing physical activity, which enhances the external excitation frequency, can lead to the fact that we can reach the maximum deflection for all rotation speeds. The maximum dynamic deflection and its related external excitation

frequency for each rotation speed decrease when the rotation speed declines.

Fig. 3 illustrates the effect of cross-section change rate on the dynamic deflection in both resonant and external excitation situations. The amount of cross-section change rate is raised from -0.4 to 0.4 with a step of 0.2. Each value of the cross-section change rate peaks at a specific frequency. Expect $\tau=-0.4$, these peaks are obtained when the ω/ω_0 was greater than one which specifies the external excitation condition where the body experiences physical exercise. The difference between these deflection peaks is quite enormous, similar to the difference in their external excitation frequency. By increasing the cross-section change rate value, the dynamic deflection peak, as well as its related external excitation frequency, would significantly rise.

As listed in Table 3, nonlocal and strain gradient parameters can affect the fundamental frequency of rotating truncated conical nanoblade carrying the nanomedicine. A strain gradient is defined as a coefficient of L which is constant and equal to 200nm. This coefficient is increased from 0 to 0.4 with a step of 0.2. The amount of the fundamental frequency extremely increases when the strain gradient grows in each step. Nevertheless, the nonlocal parameter has the opposite impact on the fundamental frequency. The nonlocal parameter is also defined as a coefficient of L. When the nonlocal parameter is equal to L, we can get the maximum fundamental frequency while the lower values of the nonlocal parameter result in a lower amount of fundamental frequency.

The impact of the strain gradient parameter on the dynamic deflection in both resonant and external excitation situations is shown in Fig. 4. Similar to the previous figures, the maximum dynamic deflection occurs for non-zero strain gradient parameter values when the body activities improve the blood flow excitation frequency. The dynamic deflection peaks are almost equal for different values of the strain gradient parameter, yet the corresponding external excitation frequencies of these peaks are different in each case. The only case where the maximum deflection occurs

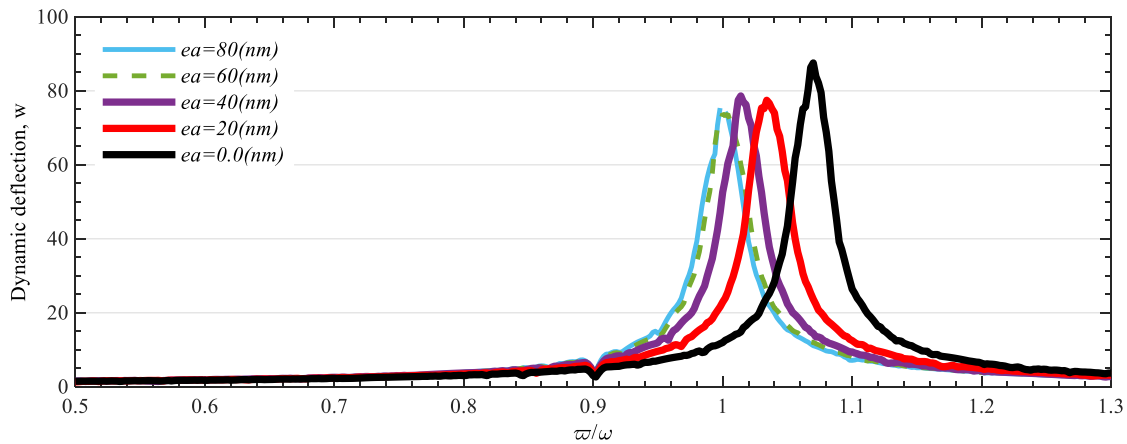


Fig. 5 Effect of nonlocal parameter (ea) on the resonant frequency ($\bar{\omega}=\omega$) and dynamic deflection ($w \times 100 G_{21} / L^4 \bar{F}$) of nonuniform nanoblade taking the nano-drug for different external excitation frequency ($\bar{\omega}$) values due to the body activities, $\bar{R}=10(\text{nm})$, $R_i=5(\text{nm})$, $L=200(\text{nm})$, $\tau=-0.1$, $\gamma=35.16 \times 10^6$, $l=2(\text{nm})$

at the resonant frequency is when the strain gradient parameter is equal to zero.

Finally, Fig. 5 depicts the impact of the nonlocal parameter on the dynamic deflection in both resonant and external excitation situations. Despite other parameters, when the nonlocal parameter increases from 0 to 80 nm, the frequency of the maximum value of dynamic deflection moves from excitation state to resonant state. The maximum deflection is almost equal for different non-zero values of nonlocal parameters, yet this value is a little higher for $ea = 0$. Comparing the highest and lowest values of the nonlocal parameter can show that the frequency of the dynamic deflection peak does not change a lot when the nonlocal parameter changes.

5. Conclusions

This paper deals with the impact of physical exercise in the form of body activities on drug delivery using nanodevices. The body's activities impact the blood flow since the nano drug delivery devices are released into the bloodstream, and physical exercise and all the activities that change the blood flow influence the stability of these nanodevices. The nanodevice for the drug delivery purpose is modeled via nonuniform tube structures based on the high-order beam theory along with the nonlocal strain gradient theory. The nanodevice is made by a central nanomotor as well as two nanoblade in the form of truncated conical nanotubes carrying the nanomedicine. The mathematical simulation of rotating nanodevices is numerically solved, and the effect of various parameters on the stability of nanodevices has been studied in detail after the validation study. The main results of this study are as follows:

- The growth of the angular velocity and the section change rate cause escalation in the fundamental frequency values.
- The maximum dynamic deflection is obtained when the rotation speed is equal to zero. This value would decline as we use a higher rotation speed until the deflection would

fall from almost 120 to 20.

- By increasing the cross-section change rate value, the dynamic deflection peak, as well as its related external excitation frequency, would significantly rise.

- The amount of the fundamental frequency, extremely increases when the strain gradient grows in each step. Nevertheless, the nonlocal parameter has the opposite impact on the fundamental frequency.

The dynamic deflection peaks are almost equal for different values of the strain gradient parameter, yet the corresponding external excitation frequencies of these peaks are different in each case.

- When the nonlocal parameter increases from 0 to 80 nm, the frequency of the maximum value of dynamic deflection moves from excitation state to resonant state. The maximum deflection is almost equal for different non-zero values of nonlocal parameters, yet this value is a little higher for $ea = 0$.

References

- Adamian, A., Safari, K.H., Sheikholeslami, M., Habibi, M., Al-Furjan, M. and Chen, G. (2020), "Critical temperature and frequency characteristics of GPLs-reinforced composite doubly curved panel", *Appl. Sci.*, **10**(9), 3251. <https://doi.org/10.3390/app10093251>.
- Adepu, S. and Ramakrishna, S. (2021), "Controlled drug delivery systems: Current status and future directions", *Molecules*, **26**(19), 5905. <https://doi.org/10.3390/molecules26195905>.
- Al-Furjan, M., Dehini, R., Khorami, M., Habibi, M. and won Jung, D. (2020a), "On the dynamics of the ultra-fast rotating cantilever orthotropic piezoelectric nanodisk based on nonlocal strain gradient theory", *Compos. Struct.*, 112990. <https://doi.org/10.1016/j.comstruct.2020.112990>.
- Al-Furjan, M., Fereidouni, M., Habibi, M., Abd Ali, R., Ni, J. and Safarpour, M. (2020b), "Influence of in-plane loading on the vibrations of the fully symmetric mechanical systems via dynamic simulation and generalized differential quadrature framework", *Eng. Comput.*, 1-23. <https://doi.org/10.1007/s00366-020-01177-7>.
- Al-Furjan, M., Moghadam, S.A., Dehini, R., Shan, L., Habibi, M. and Safarpour, H. (2020c), "Vibration control of a smart shell

- reinforced by graphene nanoplatelets under external load: Semi-numerical and finite element modeling”, *Thin Wall. Struct.*, **107**242. <https://doi.org/10.1016/j.tws.2020.107242>.
- Alimardani, V., Abolmaali, S.S., Yousefi, G., Rahiminezhad, Z., Abedi, M., Tamaddon, A. and Ahadian, S. (2021), “Microneedle arrays combined with nanomedicine approaches for transdermal delivery of therapeutics”, *J. Clinic. Med.*, **10**(2), 181. <https://doi.org/10.3390/jcm10020181>.
- Ansari, A.A., Parchur, A.K., Thorat, N.D. and Chen, G. (2021), “New advances in pre-clinical diagnostic imaging perspectives of functionalized upconversion nanoparticle-based nanomedicine”, *Coordinat. Chem. Rev.*, **440** 213971. <https://doi.org/10.1016/j.ccr.2021.213971>.
- Azimi, M., Mirjavadi, S.S., Shafiei, N. and Hamouda, A.M.S. (2016), “Thermo-mechanical vibration of rotating axially functionally graded nonlocal Timoshenko beam”, *Appl. Phys. A*, **123**(1), 104. <https://doi.org/10.1007/s00339-016-0712-5>.
- Azimi, M., Mirjavadi, S.S., Shafiei, N., Hamouda, A.M.S. and Davari, E. (2018), “Vibration of rotating functionally graded Timoshenko nano-beams with nonlinear thermal distribution”, *Mech. Adv. Mater. Struct.*, **25**(6), 467-480. <https://doi.org/10.1080/15376494.2017.1285455>.
- Bernal, A., Calcagno, C., Mulder, W.J. and Pérez-Medina, C. (2021), “Imaging-guided nanomedicine development”, *Curr. Opinion Chem. Biol.*, **63**, 78-85. <https://doi.org/10.1016/j.cbpa.2021.01.014>.
- Bruno, F., Granata, V., Cobiانchi Bellisari, F., Sgalambro, F., Tommasino, E., Palumbo, P., Arrigoni, F., Cozzi, D., Grassi, F. and Brunese, M.C. (2022), “Advanced Magnetic Resonance Imaging (MRI) Techniques: Technical principles and applications in nanomedicine”, *Cancers*, **14**(7), 1626. <https://doi.org/10.3390/cancers14071626>.
- Cai, S.S., Li, T., Akinade, T., Zhu, Y. and Leong, K.W. (2019), “Drug delivery carriers with therapeutic functions”, *Adv. Drug Deliv. Rev.*, **176**, 113884. <https://doi.org/10.1016/j.addr.2021.113884>.
- Cao, C., Wang, J., Kwok, D., Cui, F., Zhang, Z., Zhang, D., Li, M.J. and Zou, Q. (2022a), “webTWAS: a resource of disease candidate susceptibility genes identified by transcriptome-wide association study”, *Nucleic Acids Res.*, **50**(D1), D1123-D1130. <https://doi.org/10.1093/nar/gkab957>.
- Cao, Z., Zhang, L., Ahmad, A.M., Alsaadi, F.E. and Anassafi, M.O. (2022b), “Adaptive neural prescribed performance control for switched pure-feedback nonlinear systems with input quantization”, *Assembl. Autom.*, **42**(6), 879-880. <https://doi.org/10.1108/AZ-05-2022-0126>.
- Chen, S., Chen, Y., Fu, M., Cao, Q., Wang, B., Chen, W. and Ma, X. (2022), “Active nanomotors surpass passive nanomedicines: Current progress and challenges”, *J. Mater. Chem. B*, **10**, 7099-7107. <https://doi.org/10.1039/D2TB00556E>.
- Cheshmeh, E., Karbon, M., Eyvazian, A., Jung, D.w., Habibi, M. and Safarpour, M. (2020), “Buckling and vibration analysis of FG-CNTRC plate subjected to thermo-mechanical load based on higher order shear deformation theory”, *Mech. Based Des. Struct.*, 1-24. <https://doi.org/10.1080/15397734.2020.1744005>.
- Dai, Z., Jiang, Z., Zhang, L. and Habibi, M. (2021a), “Frequency characteristics and sensitivity analysis of a size-dependent laminated nanoshell”, *Adv. Nano Res.*, **10**(2), 175. <https://doi.org/10.12989/anr.2021.10.2.175>.
- Dai, Z., Zhang, L., Bolandi, S.Y. and Habibi, M. (2021b), “On the vibrations of the non-polynomial viscoelastic composite open-type shell under residual stresses”, *Compos. Struct.*, 113599. <https://doi.org/10.1016/j.compstruct.2021.113599>.
- De Lázaro, I. and Mooney, D.J. (2021), “Obstacles and opportunities in a forward vision for cancer nanomedicine”, *Nature Mater.*, **20**(11), 1469-1479. <https://doi.org/10.1038/s41563-021-01047-7>.
- Díez, P., Lucena-Sánchez, E., Escudero, A., Llopis-Lorente, A., Villalonga, R. and Martínez-Manez, R. (2021), “Ultrafast directional Janus Pt-mesoporous silica nanomotors for smart drug delivery”, *ACS Nano*, **15**(3), 4467-4480. <https://doi.org/10.1021/acsnano.0c08404>.
- Ebrahimi, F. and Shafiei, N. (2016), “Application of Eringen's nonlocal elasticity theory for vibration analysis of rotating functionally graded nanobeams”, *Smart Struct. Syst.*, **17**(5), 837-857. <https://doi.org/10.12989/sss.2016.17.5.837>.
- Ebrahimi, F. and Shafiei, N. (2017), “Influence of initial shear stress on the vibration behavior of single-layered graphene sheets embedded in an elastic medium based on Reddy's higher-order shear deformation plate theory”, *Mech. Adv. Mater. Struct.*, **24**(9), 761-772. <https://doi.org/10.1080/15376494.2016.1196781>.
- Ebrahimi, F., Shafiei, N., Kazemi, M. and Mousavi Abdollahi, S.M. (2017), “Thermo-mechanical vibration analysis of rotating nonlocal nanoplates applying generalized differential quadrature method”, *Mech. Adv. Mater. Struct.*, **24**(15), 1257-1273. <https://doi.org/10.1080/15376494.2016.1227499>.
- Ehyaei, J., Akbarshahi, A. and Shafiei, N. (2017), “Influence of porosity and axial pressure on vibration behavior of rotating FG nanobeam”, *Adv. Nano Res.*, **5**(2), 141. <https://doi.org/10.12989/anr.2017.5.2.141>.
- Gao, C., Fang, Y., Wilson, D.A., Tu, Y. and Peng, F. (2022), “Micro-nano motors with taxis behavior: Principles, designs, and biomedical applications”, *Small*, **18**(15), 2106263. <https://doi.org/10.1002/smll.202106263>.
- Gao, W. and Wang, J. (2014), “Synthetic micro/nanomotors in drug delivery”, *Nanoscale*, **6**(18), 10486-10494. <https://doi.org/10.1039/C4NR03124E>.
- Gan, H.N., Murugan, D.D., Chik, Z., Norazit, A., Foo, Y.Y., Leo, B.F., Leo, Y.Y., Abdul, S.Z.S.B.S., Chan, Y. and Chai, H.J. (2022), “Renal Nano-drug delivery for acute kidney Injury: Current status and future perspectives”, *J. Control. Release*, **343**, 237-254. <https://doi.org/10.1016/j.jconrel.2022.01.033>.
- Ghadiri, M., Hosseini, S.H.S. and Shafiei, N. (2016a), “A power series for vibration of a rotating nanobeam with considering thermal effect”, *Mech. Adv. Mater. Struct.*, **23**(12), 1414-1420. <https://doi.org/10.1080/15376494.2015.1091527>.
- Ghadiri, M., Mahinzare, M., Shafiei, N. and Ghorbani, K. (2017a), “On size-dependent thermal buckling and free vibration of circular FG Microplates in thermal environments”, *Microsyst. Technol.*, **23**(10), 4989-5001. <https://doi.org/10.1007/s00542-017-3308-x>.
- Ghadiri, M. and Shafiei, N. (2016a), “Nonlinear bending vibration of a rotating nanobeam based on nonlocal Eringen's theory using differential quadrature method”, *Microsyst. Technol.*, **22**(12), 2853-2867. <https://doi.org/10.1007/s00542-015-2662-9>.
- Ghadiri, M. and Shafiei, N. (2016b), “Vibration analysis of a nano-turbine blade based on Eringen nonlocal elasticity applying the differential quadrature method”, *J. Vib. Control*, **23**(19), 3247-3265. <https://doi.org/10.1177/1077546315627723>.
- Ghadiri, M. and Shafiei, N. (2016c), “Vibration analysis of rotating functionally graded Timoshenko microbeam based on modified couple stress theory under different temperature distributions”, *Acta Astronaut.*, **121**, 221-240. <https://doi.org/10.1016/j.actaastro.2016.01.003>.
- Ghadiri, M., Shafiei, N. and Akbarshahi, A. (2016b), “Influence of thermal and surface effects on vibration behavior of nonlocal rotating Timoshenko nanobeam”, *Appl. Phys. A*, **122**(7), 673. <https://doi.org/10.1007/s00339-016-0196-3>.
- Ghadiri, M., Shafiei, N. and Alavi, H. (2017b), “Thermo-mechanical vibration of orthotropic cantilever and propped cantilever nanoplate using generalized differential quadrature method”, *Mech. Adv. Mater. Struct.*, **24**(8), 636-646. <https://doi.org/10.1080/15376494.2016.1196770>.

- Ghadiri, M., Shafiei, N. and Alavi, H. (2017c), "Vibration analysis of a rotating nanoplate using nonlocal elasticity theory", *J. Solid Mech.*, **9**(2), 319-337.
- Ghadiri, M., Shafiei, N. and Alireza Mousavi, S. (2016c), "Vibration analysis of a rotating functionally graded tapered microbeam based on the modified couple stress theory by DQEM", *Appl. Phys. A*, **122**(9), 837. <https://doi.org/10.1007/s00339-016-0364-5>.
- Ghadiri, M., Shafiei, N. and Babaei, R. (2017d), "Vibration of a rotary FG plate with consideration of thermal and Coriolis effects", *Steel Compos. Struct.*, **25**(2), 197-207. <https://doi.org/10.12989/SCS.2017.25.2.197>.
- Ghadiri, M., Shafiei, N. and Safarpour, H. (2017e), "Influence of surface effects on vibration behavior of a rotary functionally graded nanobeam based on Eringen's nonlocal elasticity", *Microsyst. Technol.*, **23**(4), 1045-1065. <https://doi.org/10.1007/s00542-016-2822-6>.
- Ghadiri, M., Shafiei, N., Salekdeh, S.H., Mottaghi, P. and Mirzaie, T. (2016d), "Investigation of the dental implant geometry effect on stress distribution at dental implant-bone interface", *J. Brazil. Soc. Mech. Sci. Eng.*, **38**(2), 335-343. <https://doi.org/10.1007/s40430-015-0472-8>.
- Giri, G., Maddahi, Y. and Zareinia, K. (2021), "A brief review on challenges in design and development of nanorobots for medical applications", *Appl. Sci.*, **11**(21), 10385. <https://doi.org/10.3390/app112110385>.
- Globus, M., Melamed, E., Keren, A., Tzivoni, D., Granot, C., Lavy, S. and Stern, S. (1983), "Effect of exercise on cerebral circulation", *J. Cerebr. Blood F Met.*, **3**(3), 287-290. <https://doi.org/10.1038/jcbfm.1983.43>.
- Gu, B., Huang, Y., Manchester, E.L., Hughes, A.D., Thom, S.A.M., Chen, R. and Xu, X.Y. (2022), "Multiphysics modelling and simulation of thrombolysis via activated platelet-targeted nanomedicine", *Pharm. Res.*, **39**(1), 41-56. <https://doi.org/10.1007/s11095-021-03161-2>.
- Guo, J., Baharvand, A., Tazeddinova, D., Habibi, M., Safarpour, H., Roco-Videla, A. and Selmi, A. (2021), "An intelligent computer method for vibration responses of the spinning multilayer symmetric nanosystem using multiphysics modeling", *Eng. Comput.*, 1-22. <https://doi.org/10.1007/s00366-021-0433-4>.
- Gupta, A., Soni, S., Chauhan, N., Khanuja, M. and Jain, U. (2022), "Nanobots-based advancement in targeted drug delivery and imaging: An update", *J. Control. Release*, **349**, 97-108. <https://doi.org/10.1016/j.jconrel.2022.06.011>.
- Habibi, M., Darabi, R., S. J. and Reis, A. (2021), "An innovation in finite element simulation via crystal plasticity assessment of grain morphology effect on sheet metal formability", *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, **235**(8), 1937-1951. <https://doi.org/10.1177/14644207211024686>.
- Hashemi, H.R., Alizadeh, A.a., Oyarhossein, M.A., Shavalipour, A., Makkiabadi, M. and Habibi, M. (2019), "Influence of imperfection on amplitude and resonance frequency of a reinforcement compositionally graded nanostructure", *Wave. Random Complex Med.*, 1-27. <https://doi.org/10.1080/17455030.2019.1662968>.
- He, X., Ding, J., Habibi, M., Safarpour, H. and Safarpour, M. (2021), "Non-polynomial framework for bending responses of the multi-scale hybrid laminated nanocomposite reinforced circular/annular plate", *Thin Wall. Struct.*, **166**, 108019. <https://doi.org/10.1016/j.tws.2021.108019>.
- Hellström, G. and Wahlgren, N.G. (1993), "Physical exercise increases middle cerebral artery blood flow velocity", *Neurosurg. Rev.*, **16**(2), 151-156. <https://doi.org/10.1007/BF00258249>.
- Herrmann, I.K., Wood, M.J.A. and Fuhrmann, G. (2021), "Extracellular vesicles as a next-generation drug delivery platform", *Nature Nanotechnol.*, **16**(7), 748-759. <https://doi.org/10.1038/s41565-021-00931-2>.
- Hou, F., Wu, S., Moradi, Z. and Shafiei, N. (2021), "The computational modeling for the static analysis of axially functionally graded micro-cylindrical imperfect beam applying the computer simulation", *Eng. Comput.*, 1-19. <https://doi.org/10.1007/s00366-021-01456-x>.
- Huang, L., Chen, F., Lai, Y., Xu, Z. and Yu, H. (2021a), "Engineering nanorobots for tumor-targeting drug delivery: From dynamic control to stimuli-responsive strategy", *Chembiochem*, **22**(24), 3369-3380. <https://doi.org/10.1002/cbic.202100347>.
- Huang, X., Hao, H., Oslub, K., Habibi, M. and Tounsi, A. (2021b), "Dynamic stability/instability simulation of the rotary size-dependent functionally graded microsystem", *Eng. Comput.*, 1-17. <https://doi.org/10.1007/s00366-021-01399-3>.
- Huang, X., Zhang, Y., Moradi, Z. and Shafiei, N. (2021c), "Computer simulation via a couple of homotopy perturbation methods and the generalized differential quadrature method for nonlinear vibration of functionally graded non-uniform microtube", *Eng. Comput.*, 1-13. <https://doi.org/10.1007/s00366-021-01395-7>.
- Huang, X., Zhu, Y., Vafaei, P., Moradi, Z. and Davoudi, M. (2021), "An iterative simulation algorithm for large oscillation of the applicable 2D electrical system on a complex nonlinear substrate", *Eng. Comput.*, 1-13. <https://doi.org/10.1007/s00366-021-01320-y>.
- Jiao, J., Choreishi, S.-m., Moradi, Z. and Oslub, K. (2021), "Couple particle swarm optimization method with genetic algorithm for the static-dynamic performance of the magneto-electro-elastic nanosystem", *Eng. Comput.*, 1-15. <https://doi.org/10.1007/s00366-021-01391-x>.
- Karaca, G.Y., Kuralay, F., Uygun, E., Ozaltin, K., Demirbiken, S.E., Garipcan, B., Oksuz, L. and Oksuz, A.U. (2021), "Gold-nickel nanowires as nanomotors for cancer marker biodetection and chemotherapeutic drug delivery", *ACS Appl. Nano Mater.*, **4**(4), 3377-3388. <https://doi.org/10.1021/acsnm.0c03145>.
- Karsauliya, K., Singh, S.P. and Sharma, M. (2022), *Nanodevices for Drug Delivery Systems*, CRC Press.
- Kawakami, S., Yasuno, T., Kawakami, S., Ito, A., Fujimi, K., Matsuda, T., Nakashima, S., Masutani, K., Uehara, Y. and Higaki, Y. (2022), "The moderate-intensity continuous exercise maintains renal blood flow and does not impair the renal function", *Physiol. Rep.*, **10**(15), e15420. <https://doi.org/10.14814/phy2.15420>.
- Kolitsi, L.I., Orova, M. and Yantsios, S.G. (2022), "A model of magnetic nanoparticle transport and their effects in tumor areas: Assessment of desirable magnetic properties", *J. Magnet. Magnet. Mater.*, 169732. <https://doi.org/10.1016/j.jmmm.2022.169732>.
- Lawson, H.D., Walton, S.P. and Chan, C. (2021), "Metal-organic frameworks for drug delivery: A design perspective", *ACS Appl. Mater. Interf.*, **13**(6), 7004-7020. <https://doi.org/10.1021/acsnami.1c01089>.
- Li, P., Yang, M. and Wu, Q. (2021), "Confidence interval based distributionally robust real-time economic dispatch approach considering wind power accommodation risk", *IEEE T. Sust. Energy*, **12**(1), 58-69. <https://doi.org/10.1109/TSTE.2020.2978634>.
- Li, Y., Li, S., Guo, K., Fang, X. and Habibi, M. (2020), "On the modeling of bending responses of graphene-reinforced higher order annular plate via two-dimensional continuum mechanics approach", *Eng. Comput.*, 1-22. <https://doi.org/10.1007/s00366-020-01166-w>.
- Liu, H., Zhao, Y., Pishbin, M., Habibi, M., Bashir, M. and

- Issakhov, A. (2021a), "A comprehensive mathematical simulation of the composite size-dependent rotary 3D microsystem via two-dimensional generalized differential quadrature method", *Eng. Comput.*, 1-16. <https://doi.org/10.1007/s00366-021-01419-2>.
- Liu, Y., Wang, W., He, T., Moradi, Z. and Larco Benítez, M.A. (2021b), "On the modelling of the vibration behaviors via discrete singular convolution method for a high-order sector annular system", *Eng. Comput.*, 1-23. <https://doi.org/10.1007/s00366-021-01454-z>.
- Liu, Z., Su, S., Xi, D. and Habibi, M. (2020a), "Vibrational responses of a MHC viscoelastic thick annular plate in thermal environment using GDQ method", *Mech. Based Des. Struct.*, 1-26. <https://doi.org/10.1080/15397734.2020.1784201>.
- Liu, Z., Wu, X., Yu, M. and Habibi, M. (2020b), "Large-amplitude dynamical behavior of multilayer graphene platelets reinforced nanocomposite annular plate under thermo-mechanical loadings", *Mech. Based Des. Struct.*, 1-25. <https://doi.org/10.1080/15397734.2020.1815544>.
- Lori, E.S., Ebrahimi, F., Supeni, E.E.B., Habibi, M. and Safarpour, H. (2020), "The critical voltage of a GPL-reinforced composite microdisk covered with piezoelectric layer", *Eng. Comput.*, 1-20. <https://doi.org/10.1007/s00366-020-01004-z>.
- Lu, P., Lee, H., Lu, C. and Zhang, P. (2006a), "Dynamic properties of flexural beams using a nonlocal elasticity model", *J. Appl. Phys.*, **99**(7), 073510. <https://doi.org/10.1063/1.2189213>.
- Lu, P., Lee, H.P., Lu, C. and Zhang, P.Q. (2006b), "Dynamic properties of flexural beams using a nonlocal elasticity model", *J. Appl. Phys.*, **99**(7), 073510. <https://doi.org/10.1063/1.2189213>.
- Ma, L., Liu, X. and Moradi, Z. (2021), "On the chaotic behavior of graphene-reinforced annular systems under harmonic excitation", *Eng. Comput.*, 1-25. <https://doi.org/10.1007/s00366-020-01210-9>.
- Mahmoudi, M. (2021), "The need for robust characterization of nanomaterials for nanomedicine applications", *Nature Commun.*, **12**(1), 5246. <https://doi.org/10.1038/s41467-021-25584-6>.
- Maina, G., Bramante, S., Borsotti, A., Oliviero, Rigardet, S. and Albert, U. (2021), "Adverse events of antipsychotics and cytochrome polymorphisms: A case series on 31 patients", *Psychiatria Danubina*, **33**(4), 522-531. <https://doi.org/10.24869/psyd.2021.522>.
- Malikan, M. and Eremeyev, Y. (2021), "Effect of surface on the flexomagnetic response of ferrie composite nanostructures: Nonlinear bending analysis", *Compos. Struct.*, **271**, 114179. <https://doi.org/10.1016/j.comstruct.2021.114179>.
- Manzari, M.T., Shamay, Y., Kiguchi, H., Rosen, N., Scaltriti, M. and Heller, D.A. (2021), "Targeted drug delivery strategies for precision medicines", *Nature Rev. Mater.*, **6**(4), 351-370. <https://doi.org/10.1038/s41578-020-00269-6>.
- Miller, C.T., Gray, W.G. and Schrefler, B.A. (2022), "A continuum mechanical framework for modeling tumor growth and treatment in two-and three-phase systems", *Arch. Appl. Mech.*, **92**(2), 461-489. <https://doi.org/10.1007/s00419-021-01891-8>.
- Mirjavadi, S.S., Afshari, B.M., Shafiei, N., Hamouda, A., Kazemi, M. and Structures, C. (2017a), "Thermal vibration of two-dimensional functionally graded (2D-FG) porous Timoshenko nanobeams", *Steel Compos. Struct.*, **25**(4), 415-426. <https://doi.org/10.12989/scs.2017.25.4.415>.
- Mirjavadi, S.S., Matin, A., Shafiei, N., Rabby, S. and Mohasel Afshari, B. (2017b), "Thermal buckling behavior of two-dimensional imperfect functionally graded microscale-tapered porous beam", *J. Therm. Stress.*, **40**(10), 1201-1214. <https://doi.org/10.1080/01495739.2017.1332962>.
- Mirjavadi, S.S., Mohasel Afshari, B., Shafiei, N., Rabby, S. and Kazemi, M. (2017c), "Effect of temperature and porosity on the vibration behavior of two-dimensional functionally graded micro-scale Timoshenko beam", *J. Vib. Control*, **24**(18), 4211-4225. <https://doi.org/10.1177/1077546317721871>.
- Mirjavadi, S.S., Rabby, S., Shafiei, N., Afshari, B.M. and Kazemi, M. (2017d), "On size-dependent free vibration and thermal buckling of axially functionally graded nanobeams in thermal environment", *Appl. Phys. A*, **123**(5), 315. <https://doi.org/10.1007/s00339-017-0918-1>.
- Mitchell, M.J., Billingsley, M.M., Haley, R.M., Wechsler, M.E., Peppas, N.A. and Langer, R. (2021), "Engineering precision nanoparticles for drug delivery", *Nature Rev. Drug Disc.*, **20**(2), 101-124. <https://doi.org/10.1038/s41573-020-0090-8>.
- Moayedi, H., Aliakbarlou, H., Jebeli, M., Noormohammadiarani, O., Habibi, M., Safarpour, H. and Foong, L. (2020a), "Thermal buckling responses of a graphene reinforced composite micropanel structure", *Int. J. Appl. Mech.*, **12**(1), 2050010. <https://doi.org/10.1142/S1758825120500106>.
- Moayedi, H., Ebrahimi, F., Habibi, M., Safarpour, H. and Foong, L.K. (2020b), "Application of nonlocal strain-stress gradient theory and GDQM for thermo-vibration responses of a laminated composite nanoshell", *Eng. Comput.*, 1-16. <https://doi.org/10.1007/s00366-020-01002-1>.
- Moayedi, H., Habibi, M., Safarpour, H., Safarpour, M. and Foong, L. (2019), "Buckling and frequency responses of a graphene nanoplatelet reinforced composite microdisk", *Int. J. Appl. Mech.*, **11**(10), 1950102. <https://doi.org/10.1142/S1758825119501023>.
- Moradi, Z., Dastgoudi, M., Ebrahimi, F. and Ehyaei, A.F. (2021), "Intelligent wave dispersion control of an inhomogeneous micro-shell using a proportional-derivative smart controller", *Wave. Random Complex Med.*, 1-24. <https://doi.org/10.1080/17455030.2021.1926572>.
- Najaian, N., Jamali, M., Habibi, M., Sadeghi, S., Jung, D.w. and Nabipour, N. (2020), "Dynamic instability responses of the substructure living biological cells in the cytoplasm environment using stress-strain size-dependent theory", *J. Biomol. Struct. Dyn.*, 1-12. <https://doi.org/10.1080/07391102.2020.1751297>.
- Oyarhossein, M.A., Alizadeh, A.a., Habibi, M., Makkiabadi, M., Daman, M., Safarpour, H. and Jung, D.W. (2020), "Dynamic response of the nonlocal strain-stress gradient in laminated polymer composites microtubes", *Sci. Rep.*, **10**(1), 1-19. <https://doi.org/10.1038/s41598-020-61855-w>.
- Paunovska, K., Loughrey, D. and Dahlman, J.E. (2022), "Drug delivery systems for RNA therapeutics", *Nature Rev. Genet.*, **23**(5), 265-280. <https://doi.org/10.1038/s41576-021-00439-4>.
- Pavlichenko, A., Smirnova, D., Susloparova, D., Syunyakov, T. and Kostyuk, G. (2021), "A one-day cross-sectional study of antidepressants prescription patterns in public mental health services: Clinical guidelines vs real clinical practice in Russia", *Psychiatria Danubina*, **33**(suppl 9), 47-54.
- Ramadon, D., McCrudden, M.T.C., Courtenay, A.J. and Donnelly, R.F. (2022), "Enhancement strategies for transdermal drug delivery systems: Current trends and applications", *Drug Deliv. Translat. Res.*, **12**(4), 758-791. <https://doi.org/10.1007/s13346-021-00909-6>.
- Rastmanesh, A., Yarak, M.T., Wu, J., Wang, Z., Ghoderao, P., Gao, Y. and Tan, Y.N. (2021), "Bioinspired micro/nanomotors towards a self-propelled noninvasive diagnosis and treatment of cancer", *Mol. Syst. Des. Eng.*, **6**(8), 566-593. <https://doi.org/10.1039/D1ME00065A>.
- Rommasi, F. and Esfandiari, N. (2021), "Liposomal nanomedicine: Applications for drug delivery in cancer therapy", *Nanosc. Res. Lett.*, **16**(1), 95. <https://doi.org/10.1186/s11671-021-03553-8>.
- Roudbari, M.A., Jorshari, T.D., Lü, C., Ansari, R., Kouzani, A.Z. and Amabili, M. (2022), "A review of size-dependent

- continuum mechanics models for micro-and nano-structures”, *Thin Wall. Struct.*, **170**, 108562.
<https://doi.org/10.1016/j.tws.2021.108562>.
- Shafiei, N., Ghadiri, M. and Mahinzare, M. (2019), “Flapwise bending vibration analysis of rotary tapered functionally graded nanobeam in thermal environment”, *Mech. Adv. Mater. Struct.*, **26**(2), 139-155.
<https://doi.org/10.1080/15376494.2017.1365982>.
- Shafiei, N., Ghadiri, M., Makvandi, H. and Hosseini, S.A. (2017a), “Vibration analysis of Nano-Rotor's Blade applying Eringen nonlocal elasticity and generalized differential quadrature method”, *Appl. Math. Modell.*, **43**, 191-206.
<https://doi.org/10.1016/j.apm.2016.10.061>.
- Shafiei, N., Hamisi, M. and Ghadiri, M. (2020), “Vibration analysis of rotary tapered axially functionally graded Timoshenko nanobeam in thermal environment”, *J. Solid Mech.*, **12**(1), 16-32.
- Shafiei, N. and Kazemi, M. (2017a), “Buckling analysis on the bi-dimensional functionally graded porous tapered nano-/micro-scale beams”, *Aerosp. Sci. Technol.*, **66**, 1-11.
<https://doi.org/10.1016/j.ast.2017.02.019>.
- Shafiei, N. and Kazemi, M. (2017b), “Nonlinear buckling of functionally graded nano-/micro-scaled porous beams”, *Compos. Struct.*, **178**, 483-492.
<https://doi.org/10.1016/j.compstruct.2017.07.045>.
- Shafiei, N., Kazemi, M. and Fatahi, L. (2017b), “Transverse vibration of rotary tapered microbeam based on modified couple stress theory and generalized differential quadrature element method”, *Mech. Adv. Mater. Struct.*, **24**(3), 240-252.
<https://doi.org/10.1080/15376494.2015.1128025>.
- Shafiei, N., Kazemi, M. and Ghadiri, M. (2016a), “Comparison of modeling of the rotating tapered axially functionally graded Timoshenko and Euler–Bernoulli microbeams”, *Physica E*, **73**, 74-87. <https://doi.org/10.1016/j.physe.2016.04.011>.
- Shafiei, N., Kazemi, M. and Ghadiri, M. (2016b), “Nonlinear vibration behavior of a rotating nanobeam under thermal stress using Eringen's nonlocal elasticity and DQM”, *Appl. Phys. A*, **122**(8), 728. <https://doi.org/10.1007/s00339-016-0249-4>.
- Shafiei, N., Kazemi, M. and Ghadiri, M. (2016c), “Nonlinear vibration of axially functionally graded tapered microbeams”, *Int. J. Eng. Sci.*, **102**, 12-26.
<https://doi.org/10.1016/j.ijengsci.2016.02.007>.
- Shafiei, N., Kazemi, M. and Ghadiri, M. (2016d), “On size-dependent vibration of porous axially functionally graded microbeam”, *Int. J. Eng. Sci.*, **101**, 29-44.
<https://doi.org/10.1016/j.ijengsci.2015.12.008>.
- Shafiei, N., Kazemi, M., Sabahi, M. and Ghadiri, M. (2016e), “Nonlinear vibration of axially functionally graded non-uniform nanobeams”, *Int. J. Eng. Sci.*, **106**, 77-94.
<https://doi.org/10.1016/j.ijengsci.2016.05.009>.
- Shafiei, N., Mirjavadi, S.S., Afshari, B.M., Rabby, S. and Hamouda, A.M.S. (2017c), “Nonlinear thermal buckling of axially functionally graded micro and nanobeams”, *Compos. Struct.*, **168**, 428-439.
<https://doi.org/10.1016/j.compstruct.2017.02.048>.
- Shafiei, N., Mirjavadi, S.S., MohaselAfshari, B., Rabby, S. and Kazemi, M. (2017d), “Vibration of two-dimensional imperfect functionally graded (2D-FG) porous nano-/micro-beams”, *Comput. Meth. Appl. Mech. Eng.*, **322**, 615-632.
<https://doi.org/10.1016/j.cma.2017.05.007>.
- Shafiei, N., Mousavi, A. and Ghadiri, M. (2016f), “On size-dependent nonlinear vibration of porous and imperfect functionally graded tapered microbeams”, *Int. J. Eng. Sci.*, **106**, 42-56. <https://doi.org/10.1016/j.ijengsci.2016.05.007>.
- Shafiei, N., Mousavi, A. and Ghadiri, M. (2016g), “Vibration behavior of a rotating non-uniform FG microbeam based on the modified couple stress theory and GDQEM”, *Compos. Struct.*, **149**, 157-169. <https://doi.org/10.1016/j.compstruct.2016.04.024>.
- Shafiei, N. and She, G.L. (2018), “On vibration of functionally graded nano-tubes in the thermal environment”, *Int. J. Eng. Sci.*, **133**, 84-98. <https://doi.org/10.1016/j.ijengsci.2018.08.004>.
- Shao, Y., Zhao, Y., Gao, J. and Habibi, M. (2021), “Energy absorption of the strengthened viscoelastic multi-curved composite panel under friction force”, *Arch. Civil Mech. Eng.*, **21**(4), 1-29. <https://doi.org/10.1007/s43452-021-00279-3>.
- Shariati, A., Mohammad-Sedighi, H., Żur, K.K., Habibi, M. and Safa, M. (2020a), “On the vibrations and stability of moving viscoelastic axially functionally graded nanobeams”, *Materials*, **13**(7), 1707. <https://doi.org/10.3390/ma13071707>.
- Shariati, A., Mohammad-Sedighi, H., Żur, K.K., Habibi, M. and Safa, M. (2020b), “Stability and dynamics of viscoelastic moving rayleigh beams with an asymmetrical distribution of material parameters”, *Symmetry*, **12**(4), 586.
<https://doi.org/10.3390/sym12040586>.
- Shivanian, E., Ghadiri, M. and Shafiei, N. (2017), “Influence of size effect on flapwise vibration behavior of rotary microbeam and its analysis through spectral meshless radial point interpolation”, *Appl. Phys. A*, **123**(5), 329.
<https://doi.org/10.1007/s00339-017-0955-9>.
- Si, Z., Yang, M., Liu, Y. and Ding, J. (2021), “Photovoltaic power forecast based on satellite images considering effects of solar position”, *Appl. Energy*, **302**, 117514.
<https://doi.org/10.1016/j.apenergy.2021.117514>.
- Singh, A.V., Chandrakar, V., Janapareddy, P., Mathews, D.E., Laux, P., Luth, A., Yang, Y., Garcia-Canibano, B., Balakrishnan, S. and Abinshed, J. (2021), “Emerging application of nanorobotics and artificial intelligence to cross the BBB: advances in design, controlled maneuvering, and targeting of the barriers”, *ACS Chem. Neurosci.*, **12**(11), 1835-1853.
<https://doi.org/10.1021/acscchemneuro.1c00087>.
- Singh, E.C., Pizzey, F.K., Askew, C.D., Mielke, G.I., Ainslie, P.N., Coombes, J.S. and Bailey, T.G. (2021), “Effects of cardiorespiratory fitness and exercise training on cerebrovascular blood flow and reactivity: A systematic review with meta-analyses”, *Am. J. Phys. Heart Circulat. Physiol.*, **321**(1), H59-H76. <https://doi.org/10.1152/ajpheart.00880.2020>.
- Sully, R.E., Moore, C.J., Garelick, H., Loizidou, E., Podoleanu, A.G. and Gubala, V. (2021), “Nanomedicines and microneedles: A guide to their analysis and application”, *Anal. Meth.*, <https://doi.org/10.1039/D1AY00954K>.
- Tang, Y., Liu, S., Deng, Y., Zhang, Y., Yin, L. and Zheng, W. (2021), “An improved method for soft tissue modeling”, *Biomed. Signal Pr. Control.*, **65**, 102367.
<https://doi.org/10.1016/j.bspc.2020.102367>.
- Tezel, G., Timur, S.S., Kuralay, F., Gürsoy, R.N., Ulubayram, K., Öner, L. and Eroğlu, H. (2021), “Current status of micro/nanomotors in drug delivery”, *J. Drug Target.*, **29**(1), 29-45.
<https://doi.org/10.1080/1061186X.2020.1797052>.
- van der Kleij, L.A., Petersen, E.T., Siebner, H.R., Hendrikse, J., Frederiksen, K.S., Sobol, N.A., Hasselbalch, S.G. and Garde, E. (2018), “The effect of physical exercise on cerebral blood flow in Alzheimer's disease”, *NeuroImage: Clinical*, **20**, 650-654.
<https://doi.org/10.1016/j.nicl.2018.09.003>.
- Varalakshmi, B., Karpagam, T., Anand, A.V. and Balamuralikrishnan, B. (2022), *Nanoscale Smart Drug Delivery Systems and Techniques of Drug Loading to Nanoarchitectures*, Springer.
- Vargason, A.M., Anselmo, A.C. and Mitragotri, S. (2021), “The evolution of commercial drug delivery technologies”, *Nature Biomed. Eng.*, **5**(9), 951-967.
<https://doi.org/10.1038/s41551-021-00698-w>.
- Wang, M., Yang, M., Fang, Z., Wang, M. and Wu, Q. (2022a), “A practical feeder planning model for urban distribution system”, *IEEE T. Power Syst.*, 1-1.

- <https://doi.org/10.1109/TPWRS.2022.3170933>.
- Wang, P., Gao, Z., Pan, F., Moradi, Z., Mahmoudi, T. and Khadimallah, M.A. (2022b), "A couple of GDQM and iteration techniques for the linear and nonlinear buckling of bi-directional functionally graded nanotubes based on the nonlocal strain gradient theory and high-order beam theory", *Eng. Anal. Bound. Elem.*, **143**, 124-136.
<https://doi.org/10.1016/j.enganabound.2022.06.007>.
- Wang, Y., Li, Z. and Hu, Q. (2021), "Emerging self-regulated micro/nano drug delivery devices: A step forward towards intelligent diagnosis and therapy", *Nano Today*, **38**, 101127.
<https://doi.org/10.1016/j.nantod.2021.101127>.
- Wang, Z., Yu, S., Xiao, Z. and Habibi, M. (2020), "Frequency and buckling responses of a high-speed rotating fiber metal laminated cantilevered microdisk", *Mech. Adv. Mater. Struct.*, 1-14. <https://doi.org/10.1080/15376494.2020.1824284>.
- Wu, J. and Habibi, M. (2021), "Dynamic simulation of the ultra-fast-rotating sandwich cantilever disk via finite element and semi-numerical methods", *Eng. Comput.*, 1-17.
<https://doi.org/10.1007/s00366-021-01396-6>.
- Xu, W., Pan, G., Moradi, Z. and Shafiei, N. (2021), "Nonlinear forced vibration analysis of functionally graded non-uniform cylindrical microbeams applying the semi-analytical solution", *Compos. Struct.*, 114395.
<https://doi.org/10.1016/j.compstruct.2021.114395>.
- Yu, X., Maalla, A. and Moradi, Z. (2022), "Electroelastic high-order computational continuum strategy for critical voltage and frequency of piezoelectric NEMS via modified multi-physical couple stress theory", *Mech. Syst. Signal Pr.*, **165**, 108373.
<https://doi.org/10.1016/j.ymssp.2021.108373>.
- Zare, R., Najaafi, N., Habibi, M., Ebrahimi, F. and Safarpour, H. (2020), "Influence of imperfection on the smart control frequency characteristics of a cylindrical sensor-actuator on GPLRC cylindrical shell using a proportional-derivative smart controller", *Smart Struct. Syst.*, **26**(4), 469-480.
<https://doi.org/10.12989/sss.2020.26.4.469>.
- Zhang, H., Wang, H., Niu, B., Zhang, L. and Ahmad, A.M. (2021a), "Sliding-mode surface-based adaptive vector-critic optimal control for switched nonlinear systems with average dwell time", *Inform. Sci.*, **580**, 756-774.
<https://doi.org/10.1016/j.ins.2021.08.062>.
- Zhang, H., Zhao, X., Wang, H., Tong, G. and Xu, N. (2022a), "Hierarchical sliding-mode surface-based adaptive Actor–critic optimal control for switched nonlinear systems with unknown perturbation", *IEEE Trans. Neural Netw. Learn. Syst.*, 1-13. <https://doi.org/10.1109/TNNLS.2022.3183991>.
- Zhang, H., Zou, Q., Ju, Y., Tong, C. and Chen, D. (2022b), "Distance-based support vector machine to predict DNA N6-methyladenine modification", *Curr. Bioinform.*, **17**(5), 473-482.
<https://doi.org/10.2174/1574893617666220404145517>.
- Zhang, Y., Wang, Z., Tazeddinova, D., Ebrahimi, F., Habibi, M. and Safarpour, H. (2021b), "Enhancing active vibration control performances in a smart rotary sandwich thick nanostructure conveying viscous fluid flow by a PD controller", *Wave. Random Complex Med.*, 1-24.
<https://doi.org/10.1080/17455030.2021.1948627>.
- Zhao, Y., Moradi, Z., Davoudi, M. and Zhuang, J. (2021), "Bending and stress responses of the hybrid axisymmetric system via state-space method and 3D-elasticity theory", *Eng. Comput.*, 1-23. <https://doi.org/10.1007/s00366-020-01242-1>.
- Zhou, C., Zhao, Y., Zhang, J., Fang, Y. and Habibi, M. (2020), "Vibrational characteristics of multi-phase nanocomposite reinforced circular/annular system", *Adv. Nano Res.*, **9**(4), 295-307. <https://doi.org/10.12989/anr.2020.9.4.295>.