Bioprinting for cancer research

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Bioprinting offers the ability to create highly complex 3D architectures with living cells. This cutting-edge technique has significantly gained popularity and applicability in several fields. Bioprinting methods have been developed to effectively and rapidly pattern living cells, biological macromolecules, and biomaterials. These technologies hold great potential for applications in cancer research. Bioprinted cancer models represent a significant improvement over previous 2D models by mimicking 3D complexity and facilitating physiologically relevant cell–cell and cell–matrix interactions. Here we review bioprinting methods based on inkjet, microextrusion, and laser technologies and compare 3D cancer models with 2D cancer models. We discuss bioprinted models that mimic the tumor microenvironment, providing a platform for deeper understanding of cancer pathology, anticancer drug screening, and cancer treatment development.

Application of bioprinting to cancer research

Cancer remains one of the most predominant life-threatening diseases in the world, with 14 million new cases of cancer and 8.2 million cancer-related deaths worldwide in 2012. The annual number of cases is predicted to rise from 14 million to 22 million over the next two decades [1]. The economic burden in the USA was US$88.7 billion in 2011 based on direct medical costs alone [American Cancer Society (2015) Economic impact of cancer (http://www.cancer.org/cancer/cancerbasics/economic-impact-of-cancer)]. There are hundreds of known types of cancer and the disease is highly complex even within a single cancer type, making the development of a single cure an astronomical task [2,3]. To gain a better understanding of cancer genesis and progression, there is a need for more complex and physiologically relevant 3D cancer models that closely mimic the in vivo tumor microenvironment. In light of these challenges, bioprinting offers the ability to form highly controllable cancer tissue models and shows potential to significantly accelerate cancer research.

2D cancer models are widely used for cancer research, contributing to our basic knowledge of cancer biology.

Protein expression [4], gene expression [5], protein gradient profiles and cell signaling [6,7], migration [8], morphology [9], proliferation [10], viability [9], organization [9], and drug response [11,12] have been shown to differ between 2D and 3D cancer models [6,13]. Although 2D cultures offer hypothetical results regarding cancer pathogenesis, it is necessary to expose cancer cells to the cell–cell and cell–matrix interactions they would experience in vivo to achieve more physiologically relevant results. Thus, cancer studies using 3D models have achieved more accurate representations of cancer tissues in terms of tumor microenvironment and biological behavior with controlled spatial distribution of cells, which is crucial for developing early diagnosis and treatment strategies for cancer.

3D printing is an additive manufacturing process by which precursor materials are deposited layer by layer to form complex 3D geometries from computer-aided designs [14–16]. A notable advantage of 3D printing is that complex architectures may be printed with efficiency and customizability either on an industrial scale or on a desktop-printing scale. 3D printing has more recently been developed into a process called bioprinting in which living cells, extracellular matrix (ECM) components, biomaterials, and biochemical factors are printed onto a receiving substrate or liquid reservoir [17–20]. The interest in bioprinting has significantly grown within the scientific and medical communities due to several key advantages over previously accepted fabrication methods such as photolithography, soft lithography, and microstamping. These advantages include the ability to create geometrically complex scaffolds containing viable cells [18,19,21], efficiency, low cost [22], high throughput [23], precise reproducibility [18], and limited need for specialized training. High-throughput fabrication of 3D structures is currently limited with traditional microfabrication techniques that generate 2D building blocks and rely on layer-by-layer assembly to form 3D structures [24–32]. Current methods for coculturing multiple cell types in desired configurations lack high-throughput capabilities, demanding multiple labor-intensive fabrication steps [23], but spatial patterning of different cell types or ECM components is possible using various ‘bio-inks’ for printing [33]. With these unique advantages, bioprinting offers a broad range of applications including biochemical surface patterning and in situ printing of biomaterials for wound healing as well as designing 3D tissue constructs for basic research.

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regenerative medicine, disease modeling, or pharmaceutical research.

This review focuses on recent advances in the use of bioprinting technologies for cancer research, bioprinting physiologically relevant testing platforms for anticancer drug development, and computational modeling for improving bioprinting techniques.

**Bioprinting techniques applied to 3D tumor models**

Within the field of bioprinting, there are several strategies by which biological organization and complexity have been successfully modeled: inkjet-based [34,35], microextrusion [36–39], and laser-assisted bioprinting [40–44] (Table 1). Inkjet-based bioprinting involves generating droplets of bio-ink at the print head assisted by either a heater or a piezoelectric actuator (Figure 1A). Microextrusion bioprinting can be achieved using either pneumatic [36–39] or mechanical (piston or screw driven) forces [36–39,45–47] to extrude a continuous stream of a bio-ink (Figure 1B). Laser-assisted bioprinting can be conducted by two methods: laser guided or laser induced. In the laser-guided direct cell-printing method, a laser beam is directed into a cell suspension. The difference in refractive indices of cells and cell media enables a laser beam to trap and guide cells onto a receiving substrate [40,48] (Figure 1C). In the laser-induced bioprinting method, which is more common, a cell-laden hydrogel is deposited below a laser-absorbing layer that is used as a donor film and placed parallel to a receiving substrate (Figure 1D). Cell-encapsulating hydrogel droplets are transferred from the donor film to the receiving substrate due to the heat transfer from a laser pulse to the donor film and the pressure of a laser-induced vapor bubble [42,44,49,50]. Stereolithography, which involves curing a photoreactive material using light, has also been used for bioprinting. Digital micromirror projection printing uses a digital micro-mirror device to reflect UV light in a particular spatial pattern into a photopolymerizable macromer solution (Figure 2A) [51]. In this way, cells can be encapsulated in and seeded on 3D-patterned hydrogel scaffolds with a range of printable materials and control over microarchitecture and scaffold properties.

**Table 1. Comparison of common bioprinting technologies**

<table>
<thead>
<tr>
<th>Performance metric</th>
<th>Microextrusion bioprinting</th>
<th>Laser-assisted bioprinting</th>
<th>Inkjet bioprinting</th>
<th>Refs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput</td>
<td>Medium</td>
<td>Low to medium</td>
<td>High</td>
<td>[23]</td>
</tr>
<tr>
<td>Droplet size</td>
<td>5 μm to millimeters wide</td>
<td>&gt;20–80 μm</td>
<td>50–300 μm</td>
<td>[23,55,88]</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>Medium</td>
<td>Medium to high</td>
<td>Medium</td>
<td>[23]</td>
</tr>
<tr>
<td>Single-cell encapsulation control</td>
<td>Medium</td>
<td>Medium to high</td>
<td>Low</td>
<td>[23]</td>
</tr>
<tr>
<td>Cell viability</td>
<td>40–80%</td>
<td>&gt;95%</td>
<td>&gt;85%</td>
<td>[55]</td>
</tr>
<tr>
<td>Cell density</td>
<td>High</td>
<td>Medium, 10⁶ cells/ml</td>
<td>Low, &lt;10⁶ cells/ml</td>
<td>[55]</td>
</tr>
<tr>
<td>Material/hydrogel viscosity</td>
<td>30 mPa.s to &gt; 600 kPa.s</td>
<td>1–300 mPa.s</td>
<td>&lt;10 mPa.s</td>
<td>[37,55]</td>
</tr>
<tr>
<td>Gelation method</td>
<td>Chemical, ionic, enzymatic, photocrosslinking, shear thinning, thermal, pH</td>
<td>Ionic</td>
<td>Ionic, enzymatic, photocrosslinking, thermal</td>
<td>[89]</td>
</tr>
<tr>
<td>Gelation speed</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>[89]</td>
</tr>
<tr>
<td>Print/fabrication speed</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>[89]</td>
</tr>
<tr>
<td>Printer cost</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>[55]</td>
</tr>
</tbody>
</table>

**Two-step biofabrication**

One method of bioprinting is a ‘two-step’ biofabrication method in which cell seeding is performed after 3D printing of the scaffold. Bioprinting can be used to generate precise biocompatible scaffolds for culturing cells with controllable structural features and composition. Digital micromirror device-based projection printing has been used to fabricate 3D polyethylene glycol (PEG) scaffolds with log-pile microarchitecture (Figure 2B–F) [52]. The elastic modulus of the scaffold was controlled by varying the PEG concentration without altering the structural or mechanical properties, allowing the effects of stiffness to be isolated and examined. Normal breast epithelial cells and Twist-transformed oncogenic cells were seeded onto the scaffold to study cell migration patterns. Cells cultured in 2D showed no statistical difference in migration on substrates with different stiffness. However, cells on 3D scaffolds demonstrated varying displacement, velocity, and path straightness depending on the scaffold stiffness and the presence of the Twist oncogene (Figure 2G–L). These results suggest that further research regarding cancer cell migration must be conducted in 3D systems.

**One-step biofabrication**

While 3D models can be generated via top-down methods by seeding cells into prefabricated scaffolds, there are limitations on controlling cell density, repeatability, spatial control, and scalability with this method [23]. In contrast to two-step bioprinting, one-step bioprinting methods print a mixture of hydrogel and cells, providing a more efficient way of fabricating 3D tissue models with less user input required [53]. A recent bioprinting technique has been shown to enable 3D patterning of human ovarian cancer (OVCAR-5) cells and normal fibroblasts on Matrigel™ with 3D complexity and spatial control over the microenvironment in terms of cell density and cell–cell distance [54]. This approach uses an automated XYZ stage with a dual ejector to position cell-encapsulating droplets at predefined locations on a substrate for high-throughput printing with high viability. OVCAR-5 cells were shown to proliferate and ultimately form acini (lobular structures) (Figure 3). Design parameters such as droplet ejection...
velocity, cell concentration, and culture duration were observed to affect acini growth kinetics after patterning. This technique accelerates the fabrication of cancer coculture models for systematic investigation of cell–cell interactions. Once regulatory mechanisms between tumor cells and their microenvironment are better understood, high-throughput and reliable drug screening can be accomplished using models fabricated using the approach presented by this study.

Constructing *in vitro* tissue models using 3D bioprinting of cells and ECM is advantageous for mimicking the biological environments of living systems. Bioprinted 3D models enhance studies regarding disease pathogenesis and drug testing. An example is a recent 3D printing method for the construction of *in vitro* cervical tumor models in which HeLa cells were encapsulated within a hydrogel mixture of gelatin, alginate, and fibrinogen [12]. In this study, HeLa cells were 3D printed with ECM materials for comparison with controls cultured in conventional 2D models. Comparison of results obtained from 2D and 3D tumor models showed differences in cell proliferation, matrix metalloproteinase (MMP) protein expression, and the chemoresistance of the cells. Over 90% cell viability was achieved in the 3D bioprinted model and the cells proliferated at a higher rate than in 2D culture. HeLa cells in 3D also formed 3D cellular spheroids in contrast to the monolayer cell sheets formed in 2D culture. These differences may originate from cell–cell and cell–matrix interactions present in 3D culture conditions. MMP protein expression in HeLa cells was also shown to be higher in 3D printed models, most likely due to the functionality of MMPs in ECM degradation.
Cells in 3D printed constructs also exhibited a higher chemoresistance against paclitaxel treatment compared with that in 2D culture. The results of this study using a novel 3D cell-printing technique to construct in vitro tumor models help to better characterize tumor formation, progression, and response to anticancer treatments [12].

Scaffold-free approaches

Another approach is scaffold-free bioprinting, involving the fusion and self-assembly of multicellular spheroids [53,55]. ECM components significantly affect tumor cell behavior, including the mode of cell migration and cell dissemination, via cell–matrix interactions [56,57]. When heterogeneous 3D tumor models with multiple cell types are constructed via scaffold-free bioprinting, cells that are co-printed with tumor cells are used to naturally produce ECM, avoiding the problem of structural differences between the proteins used and the varying composition and material properties associated with exogenous scaffolds [58]. Thus, independent physiological interactions between cells and matrix can be more directly understood.

In a recent study using a scaffold-free method, breast cancer neotissues (newly formed tissues) were bioprinted
without a supportive scaffold [58]. Breast cancer cells were deposited along with fibroblasts, adipocytes, and endothelial cells in spatially definitive patterns to mimic breast tumor stroma. In these models, stromal cells were shown to secrete ECM, growth factors, and hormones, resulting in natural localization and function of the cells in a biomimetic tumor microenvironment. The bioprinted neotissues remained viable for more than 14 days and differentiation of adipocytes and formation of endothelial networks were observed. Histomorphological analysis showed adipose, stromal, epithelial, and carcinoma compartmentalization. 3D neotissue models were more resistant to chemotherapeutic agents compared with 2D-cultured cancer cells. Thus, these 3D neotissue models were validated as another useful tool for representing in vivo microenvironmental conditions and screening new anticancer therapies [58].

**Optimizing cell viability**

Cell survival rate after printing may be optimized by adjusting printing parameters such as applied pressure, nozzle diameter and temperature (in techniques using a nozzle), viscosity of the suspending medium, and environmental conditions [12,59]. Other parameters such as deformation of cell-encapsulating droplets, surface tension, and the hydrophobicity/hydrophilicity of the substrate have also been identified and evaluated via computational simulation and modeling. Further advanced computational
models can help researchers by identifying experimental conditions (such as the material properties of the encapsulating and surrounding media and ejection velocity), directing future research toward optimal viability. One additional important parameter is the duration of the bioprinting process. The viability of encapsulated cells is impacted by: (i) the waiting time of cells within the pre-gel bio-ink during fabrication; (ii) the waiting time of cells within the deposited construct during fabrication before incubation; and (iii) the sensitivity of different cell types to these external stresses. One potential approach to maximize viability is to use multinozzle printheads [60], which co-print cell-laden hydrogels simultaneously, decreasing the printing time [59].

**Computational modeling for bioprinting**

Computational simulations coupled with experimental tests can help in understanding the effects of experimental printing parameters on post-printing cell viability. Modeling and experimenting with double emulsion systems, which are fluid systems of emulsion droplets enclosing smaller inner droplets [61,62], are promising to develop a better understanding of the cell-printing process. A recent study combining experimental investigation with computational simulation revealed an intensification of the transient deformation oscillation of a double emulsion droplet under shear caused by the hydrodynamic effects of the inner droplet [61]. The inner droplet co-induces enhancing and suppressing effects on the deformation of the double emulsion droplet. These competing effects cause the double emulsion droplet to experience both larger and smaller steady deformation compared with the single-phase droplet. The dominant regime of the competing effects on deformation is determined by the ratio of the inner droplet radius to the outer droplet radius and the capillary number, representing the competition of viscous

Figure 4. 3D printing method for HeLa cells and characterization compared with 2D planar culture. (A) Workflow of the 3D cell-printing process to fabricate 3D HeLa/alginate/fibrinogen constructs. (B) Top view of 3D HeLa/alginate/fibrinogen constructs on day 0, day 5, and day 8. Scale bar, 5 mm. (C) Cellular morphological changes were characterized by staining cell filaments and nuclei on day 5 and day 8 in 3D constructs and 2D planar cultures. Scale bar, 50 μm. (D) Semiquantitative analysis of matrix metalloprotease (MMP)-2 and -9 secretion shows the difference in MMP secretion of HeLa cells in 3D constructs versus 2D planar culture. *P < 0.05; t-test. (E) Chemoresistance of HeLa cells in 3D HeLa/alginate/fibrinogen constructs and 2D planar culture on day 5 (the time of first addition of paclitaxel) and after paclitaxel treatment, as measured by cellular metabolic activity. Reproduced, with permission, from [12].
shear stress with interface tension. The deformation, \( D = (L - B)/(L + B) \), gives the degree of deformation of a droplet (\( D \)) as a function of the half-length (\( L \)) and half-breadth (\( B \)) of the best-fit ellipse approximating the droplet (Figure 5A). Experimental results along with computational simulations in this study provide a better understanding of hydrodynamic effects on the deformation of the double emulsion droplet [62], mimicking cell-encapsulating droplets.

Ejected cell-laden droplets experience significant hydrodynamic pressures, capillary forces, and shear stresses when landing on a substrate [63] (Figure 5B,C). When these mechanical stresses reach a certain threshold, cells may undergo apoptosis. However, these forces can be minimized by optimizing the ejection velocity or by changing the material properties of the encapsulating fluid. Cell fate may also depend on the hydrophobicity/hydrophilicity of the receiving surface, which is highly correlated with the contact angle between the droplet medium and the surface. Simulations can aid in predicting cell fate and provide more parametric control over 3D cancer models as well as complex viable tissue surrogates.

A finite-difference/front-tracking simulation model of viscous compound droplet deposition onto a receiving surface was presented as a model for cell printing [64–66]. Several parameters such as Weber number (\( W_e \)), diameter ratio (\( d_d/d_i \)), viscosity ratio (\( \mu_d/\mu_a \)), Reynolds number (\( R_e \)), surface tension ratio (\( \sigma_d/\sigma_a \)), and equilibrium contact angle (\( \theta_e \)) were studied to monitor cell deformation during cell printing. \( W_e \) and \( R_e \) are widely used nondimensional numbers in fluid dynamics [67] that evaluate the influences of inertial forces compared with surface tension and viscous forces, respectively [68,69]. The computational results demonstrated that the geometric deformation of a cell monotonically increased: (i) as \( d_d/d_i \) decreased; (ii) as \( \theta_e \) decreased; (iii) as \( \sigma_d/\sigma_i \) increased; (iv) as \( R_e \) increased; or (v) as \( \mu_d/\mu_a \) decreased. A local minimum of predicted values for maximum geometric deformation was obtained at \( W_e = 2 \). Results demonstrated that \( \theta_e \) and \( \mu_d/\mu_a \) were also strongly correlated with cell fate.
Next-generation models should incorporate non-Newtonian features of fluid flows [70,71], smaller contact angles, microstructured models of cells, and multiple patterning of droplets. Such computational models can accelerate the incorporation of bioprinting technologies into cancer research and help to develop more precise and reliable anticancer drug delivery systems.

**Investigating cancer processes using bioprinting**

**Tumor heterogeneity**

The heterogeneity and complexity of the tumor microenvironment can be replicated by co-printing bio-inks with different cell types, ECM, and biomolecules [33]. Heterologous constructs containing tumor cells, endothelial cells, and macrophages can be fabricated with a high degree of spatial control via bioprinting to replicate physiologically relevant cell–cell interactions. In these constructs, the initial cell density can also be controlled to closely mimic the high cell density of a tumor and replicate the cell–cell signaling that is known to have a significant role in cancer cell behavior [54]. In addition, co-printed 3D models of cancer cells and blood vessels allow real-time monitoring of the process of cancer metastasis, including tumor cell intravasation. A wide range of cancer types can be studied by printing different combinations of cancer cell types and surrounding cells to model cancer metastasis in a range of different tissue types, simply by reformulating the bio-ink. Biomolecule gradients, which play an important role in chemotaxis and cancer metastasis, can be generated using 3D printing methods to reveal molecular mechanisms of biochemical signaling [53,72,73].

**Angiogenesis and tumor vasculature**

One study proposed a novel method to examine cell behavior and screen potential new drugs. In this research, cancer and normal cells were seeded into 3D-printed biomimetic microstructures to study cell migration differences among cell types [74]. Here, 3D vascularization was achieved by printing a 3D microscaffold model based on a microcomputed tomography scan of rat capillaries in three different channel widths (25, 45, and 120 μm) to mimic the range of blood vessel diameters in vivo. These biomimetic models can be used to test the difference between normal and cancerous cell responses to antimitogenic drugs [74].

Leaky (relatively permeable) [75,76] and poorly organized [77,78] vessel formation are distinctive features of cancerous tumors [79]. The notable differences between cancer and healthy vessels affect drug delivery in these tissues, necessitating that drug delivery be tested using leaky-vessel models to optimize the particle size and dosage of anticancer drugs [79,80]. Taking advantage of the spatial control over cell distribution using bioprinting, future work may aim to generate a 3D model for leaky vessels feeding a tumor compared with vessels in healthy tissue [54,79].

**Tumor spheroid formation**

3D projection printing has been used to generate concave PEG structures that form and maintain breast cancer spheroids [81]. The 3D projection printing technique was modified by the use of nonlinear UV light and a circular gradient exposure pattern such that the center receives little UV exposure relative to the edge of the circle, generating 3D concave structures. When BT474 breast cancer cells were seeded on these structures, spheroids formed with a narrow distribution of size compared with flat cultures. These spheroids exhibited hollow necrotic cores with high expression of HIF-1α, a biomarker for hypoxia, which is consistent with results previously observed for tumor spheroids. This 3D-printed platform may serve as a low-cost, highly reproducible, physiologically relevant tumor model for studying tumor progression, migration, and angiogenesis with the ability to maintain spheroids in long-term culture.

**Bioprinting for anticancer drug development**

Initial work using bioprinting to create 3D models for drug development includes the printing of cell-laden Matrigel constructs and incorporation of these constructs into microfluidic devices [82]. This study focused on multicellular prodrug conversion and liver radioprotection using the prodrug amifostine, which is a drug precursor carrying a parent compound to enhance solubility and targeting before conversion into the active form. The fabrication method was based on temperature-controlled bioprinting of pre-gels (such as Matrigel and collagen) into prefabricated PDMS substrates [82]. Progress in this field led to bioprinting technologies being used for anticancer drug development by creating physiologically relevant 3D human carcinoma models [12,83].

To establish novel treatments and acquire FDA approval for new drugs, studies conducted in conventional ways may extend up to 15 years and require a budget of US$2.6 billion [Bright Focus Foundation (2014) Understanding clinical trials (http://www.brightfocus.org/understanding-clinical-trials-overview.html); Peters, S. and Lowy, P. (2014) Cost to develop and win marketing approval for a new drug is $2.6 billion. Tufts Center for the Study of Drug Development (http://cscd.tufts.edu/news/complete_story/pr_tufts_cscd_2014_cost_study)]. Ultimately, one in five proposed drugs that reach clinical testing obtain FDA approval [Bright Focus Foundation (2014) Understanding clinical trials (http://www.brightfocus.org/understanding-clinical-trials-overview.html)]. In addition, the results from testing on animal models may not accurately predict the result in human testing due to cross-species differences [84], causing many drugs to fail in the clinical trial stage. Furthermore, animal testing raises ethical concerns and this ethical framework is closely regulated to control the use of animals for scientific research [85].

3D-bioprinted tumor models are excellent candidates to replace or supplement animal testing before human trials, as bioprinting enables repeatability of testing, close biomimicry, and high-throughput fabrication capabilities. New drug delivery systems can be tested for the biodegradability of drug carriers such as polymer microspheres and drug-release kinetics using in vitro cancer models before animal or human testing [80,86]. The efficacy of a drug treatment in vivo can be well predicted by examining its effect on the bioprinted model. The repeatability of bioprinting 3D cancer models contributes to the development of 3D-printed cancer models as an industry standard [87].
Concluding remarks and future perspectives

Here we discuss recently developed 3D printing techniques to emulate a 3D tumor environment. A key advantage of the 3D microenvironment over traditional 2D cell culture is the ability to obtain more accurate and reliable data from the model. Studies using 3D in vitro cancer models rather than 2D models show greater cell viability, more physiologically relevant protein expression profiles, higher proliferation rate, higher chemoresistance to anticancer drugs, and characteristics of real tumors (e.g., presence of necrotic cores). Bioprinting of heterologous cells in 3D has the potential for better in vitro modeling of the tumor microenvironment with high viability and 3D control over the spatial distribution of cells. High-throughput fabrication helps to better characterize tumor formation, progression, and response to anticancer therapies [12].

The absence of a direct correlation between the genetics and physiology of animal models and humans currently limits our understanding of how cancer cells behave in humans. Living microarchitectures bioprinted from human cells are more realistic for creating disease models. In the interest of developing more effective anticancer treatments, an ample amount of information remains to be discovered and these studies can be accelerated using bioprinted cancer models. Current bioprinting applications for cancer research are promising to establish new experimental procedures for the fabrication of 3D cancer models to pursue new discoveries in cancer biology or test clinical therapeutics. Further studies in bioprinting will enable high-throughput fabrication of 3D cancer models for elucidating the underlying mechanisms of cancer progression, studying cancer cell behavior, screening drugs, and developing effective clinical treatments.

These modeling systems have the potential to be the experimental bridges to new clinical techniques by which a tumor model specific to a patient can be created in vitro. Bio-inks can be generated by proliferating cancer cells taken from a donated tumor sample or a tumor bank. After printing with these bio-inks, cells form their natural network and tumor tissue, on which new cancer drugs and treatments can be tested [John, G. (2013) Organovo using 3D bioprinting to push cancer research to new levels (http://www.3dprinterworld.com/article/organovo-using-3d-bioprinting-push-cancer-research-new-levels)]. This would make it possible to test drug therapies in vitro, giving information about the most effective drug type and dosage and developing a personalized cancer treatment for the patient.

Acknowledgments

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