Research landscape on 3D printing applications in healthcare within Southeast Asian countries: a systematic scoping review protocol

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STRENGTHS AND LIMITATIONS OF THIS STUDY
⇒ This protocol will provide the assurance of reliability to the scoping study of three-dimensional (3D) printing technology in healthcare research in the Southeast Asian region.
⇒ This scoping review will be the first scoping review about the application of healthcare research on 3D printing technology within the Southeast Asian context.
⇒ The identification and synthesis of data will be expanded from the published papers from five electronic databases and include the grey literature sources such as theses and conference proceedings.
⇒ The findings of this scoping review may not adequately reflect the overall 3D printing activities in Southeast Asia but merely as a rough indication of the overall 3D printing activities for each Southeast Asian country.
⇒ The review only includes published literature in English and Malay and does not feature any other languages.

INTRODUCTION
The fourth industrial revolution (IR 4.0) is emerging from the era of industrial digitalisation in various sectors worldwide, and three-dimensional (3D) printing is one of the important features of IR 4.0. 3D printing (or additive manufacturing) is the method that develops 3D objects by fusing layers in a row via a two-dimensional cross section manner and it is a set of procedures that link controlled materials together to construct a 3D object. This is in contrast to the traditional subtractive manufacturing in which designs were sculpted out of a solid block of material to produce a two-dimensional object. Recent advances in the available materials, speed, resolution, accuracy, reliability, cost and repeatability of 3D printing technologies have broadened the possibilities of implementing such technologies for clinical or medical uses.

The global market for 3D printing is predicted to increase its revenue from US$12.6 million in 2021 to US$34.8 billion by 2026, and the worldwide compound annual growth rate for the market of 3D printing...
in healthcare is forecast to be 18.2% between 2019 and 2026. One of the key factors which can drive the market growth includes technological advancements in 3D printing which result from customisation and personalisation to suit the unique needs of each patient from a large patient pool in the population. The geographical analysis of the market for 3D printing within the healthcare industry had reported that North America dominated the global market internationally in terms of revenue and industry had reported that North America dominated the market for 3D printing within the healthcare industry; according to a survey by International Data Corporation, these countries are paving their way towards enhanced advocacy of additive manufacturing for end parts, particularly in the aerospace and healthcare industries. Additionally, some of these Western European countries have also developed a national strategy for additive manufacturing as a part of their advanced manufacturing and industry 4.0 plans.

In the Asia-Pacific region, China is the major determinant of the future for 3D printing in healthcare applications within the regional market, which is bolstered by the immense industrial capacity, constructive policies and research and development (R&D) expenditure from the Chinese government. Meanwhile, South Korea and Singapore play a major role in driving the Asia-Pacific market for 3D bioprinting while India and Japan for 3D printing of orthopaedic equipment, which caters to an increased demand from the ageing population. Henceforth, the Asia-Pacific 3D printing industry is expected to expand by 21.4% from 2020 to 2030, with an overall addressable market size of US$58.83 million despite the negative impact of the recent COVID-19 pandemic outbreak. This depicts the Asia-Pacific as the key region for potential 3D printing activity, primarily dominated by South Korea, China and Japan, which currently contribute to 21% of the global market share. This growth potential is supported by an extensive industrial base, supportive government policies and funding in R&D, while both Japan and China are particularly noteworthy in terms of government initiatives and rapid growth in this field.

Future development of healthcare advancement application of 3D printing has been widely acknowledged within Southeast Asia by various Association of Southeast Asian Nation countries even though the penetration of 3D printing in the Southeast Asian market is considered relatively small regardless of extensive recognition worldwide. Generally, the highest level of 3D printing applications in the Southeast Asian market is led by the Republic of Singapore with 40%, followed by Thailand with 25% and Malaysia with 15%, while Myanmar, Laos and Brunei each with 1% and with minimal 3D printing adaptations. Nonetheless, Southeast Asia is an emerging region in the medical sector, with a market capitalisation of US$71 billion and a year-on-year growth rate of 15%. However, 3D printing accounts for just 3% of global healthcare spending despite having 10% of the world’s population, and within this 3%, 3D printing in Southeast Asia only represents 5%–7% of Asia’s total expenditure. Hence, this could explain the absence of sufficient updated information on the progress of 3D printing within the Southeast Asian region.

The fullest extent for both the utility and overall applicability as well as future direction of 3D printing may still seem incongruous, especially in the healthcare sector despite the gradual increment of 3D printing utilisation within the Southeast Asian region, although 3D printing technology has been successfully used in medicine within the Southeast Asian region; however, to the best of our knowledge, there is limited evidence regarding the landscape of 3D printing technology and its applications within the Southeast Asian healthcare industry. In addition, there is currently still insufficient information that can be found from the countries with low activity rates such as Laos, Myanmar and Brunei regarding their level of participation in the utilisation of 3D printing for the delivery of healthcare applications. Furthermore, most of the existing systematic reviews or scoping reviews are focusing on the utility and applicability of 3D printing technology for a specific medical or surgical discipline, or the diagnosis and/or treatment of a particular disease or group of diseases, thus it appears that there is still a dearth of published literature which examines the broad outlook or landscape of 3D printing technology and its applications for the entire healthcare industry within a particular geographical location especially Southeast Asia. In addition, a white paper from ThyssenKrupp reported that 3D printing can potentially enhance the overall competitiveness of Southeast Asia by focusing on efforts with an impact on their global competitiveness, which is commonly driven by customisation, low expenditure, faster time to market and high quality in the 3D printing global market. Therefore, it is paramount to map evidence from various sources of published literature on 3D printing from Southeast Asia to elucidate the progress of overall utilisation of 3D printing technology by the healthcare industry within all Southeast Asian countries and also to provide an outlook on the landscape of 3D printing technology and its applications based on a careful perusal of academic publications from all over this geographical region. According to Vincent-Lancrin, academic research is defined as R&D conducted in the higher education sector. Another significant progress in academic research during the last two decades has been the expansion of R&D output. It is strongly linked to and possibly fully explained by the rise in R&D expenditure and the number of researchers in the higher education sector such as universities and research centres. Hence,
R&D activity is clearly influenced by the trend and market driven towards the future direction of the current landscape on academic research especially in 3D printing technology in healthcare sector.

Therefore, we aim to conduct a scoping review to identify and synthesise the existing areas of focus for 3D printing technology and its application within the healthcare industry among all these Southeast Asian countries. The synthesis of research evidence in this study is essential in providing an overview of the landscape of 3D printing technology in Southeast Asia, as well as to compare it among the various Southeast Asian countries. This also could be used to reflect the direction of 3D printing technology and the attendant economic activity in the Southeast Asian region. Therefore, by adopting the conventional approach towards conducting a scoping review by Arksey and O’Malley,21 we look forward to successfully retrieving the findings of this scoping review that will enable us to catch a glimpse of the future directions of 3D printing technology in the healthcare sector within Southeast Asia. This can be achieved by first identifying published studies on 3D printing technology in healthcare within this geographical region and by doing so, we can hopefully sift through relevant findings from these studies that will assist the researchers, government delegations and policymakers from this region to assess the current prospects and future directions of 3D printing technology within the regional healthcare industry. It is also anticipated that the results of this scoping review will portray an excellent overview of the importance of 3D printing advancement in healthcare, thus implementing such applications in hospitals, clinics and health institutions around the Southeast Asian region. An important ramification of the findings obtained from this scoping review is to compare the amount of published literature pertaining to the utility and applicability of 3D printing technology in the healthcare industry among various countries within Southeast Asia, as well as between Southeast Asia and the other parts of the world.

**MATERIALS AND METHODS**

The methodology for this scoping review has drawn on Arksey and O’Malley’s seminal framework for mapping the essential concepts rapidly that drive a research area, as well as the primary sources and types of evidence that are accessible.21 The framework provided by Arksey and O’Malley is often regarded as the pioneering; a framework for clarifying the usage and adoption of a scoping review methodology by postulating a starting point towards an evolitional methodological framework.22 23 Later, the augmented advancement to the previous methodology redefined by Levac et al and Colquhoun et al also will be employed in this scoping review to further consolidate the interpretation of the findings. Consequently, this scoping review encompasses five major steps as follows: (1) identifying the research question; (2) identifying relevant studies; (3) selecting eligible studies; (4) charting the data; and (5) collating, summarising and reporting the findings. As suggested by Arksey and O’Malley, an optional step involves the consultation with experts and key stakeholders for obtaining a comprehensive coverage of the findings beyond the up-to-date literature by incorporating important perspectives of experts and key stakeholders. However, we did not undertake this optional step due to both resource and time constraints. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Extension for Scoping Reviews checklist and recommendation (see checklist) will be adhered to by this scoping review in order to conform to a standardised approach for conducting specific types of knowledge synthesis and also to identify the knowledge gaps by applying the evidence maps which include both a systematic search of the body of literature and a visual presentation of outcomes.26 The protocol of this scoping review is registered with Open Science Framework, available at osf.io/3u4d4.

**Identifying the research questions**

Research questions for the scoping review usually focus on delineating the breadth of evidence, and thus the research questions should be broad in nature and well defined to provide extensive coverage.24 27 For our scoping review, two major research questions underpin the discussion which is generated by the scoping review findings. They are as follows:

- What are the types of research that have been published for 3D printing in healthcare from Southeast Asian countries?
- What is the focus and direction of each Southeast Asian country on 3D printing in healthcare?

As for the first research question, the research team is interested to identify the various types of research that have been published pertaining to 3D printing, especially in the healthcare sector. In the context of a healthcare setting, the types of research will focus on the clinical background of the researchers either in the setting of a hospital or a research institution. This will be followed by the research condition, that is, either involving patients for delivering applications of 3D printing technology or delivering such applications without patients (e.g., only involving 3D prototype or computer-aided design). Next, the second research question for the scoping review is to unravel the focus and direction of each Southeast Asian country on the application of 3D printing technology in healthcare. This is important to discover the extent of such implementation within the various medical categories.

Thus, the above research questions are directly aligned with our objectives of this scoping review, which are to map the existing research evidence of 3D printing in healthcare in Southeast Asia; to establish the comparison of 3D printing in healthcare research among the countries; and to determine the healthcare focus and priority setting in 3D printing technology of each of these Southeast Asian countries.
Identifying relevant studies

A search will be conducted using the electronic databases indexed in PubMed/MEDLINE, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Scopus, ProQuest and Web of Science. Optimal searches for a systematic review should rightfully include MEDLINE and Web of Science as a minimum requirement to provide adequate and effective coverage while CINAHL can also be included as a special topic database for which the topic of the review has directly linked to the major focus of a specialised subject database because CINAHL is a standard research tool for nursing and allied health professionals. Also, both Scopus and Web of Science have been examined to be suitable for synthesising evidence for systematic reviews and can be used as primary search systems. ProQuest is a database research website that portrays itself to be an independent and entirely accessible database that offers access to numerous full-text articles from a variety of academic journals. Additionally, a range of grey literature such as theses and dissertations, proceedings and conference abstracts will be also included in this scoping review to minimise publication bias, improve the thoroughness and timeliness of the review and promote a realistic overview of the presented evidence. Also, grey literature can help retrieve the important 3D printing studies that either are not or have not yet been published and/or preliminary or relevant findings that were still published in the conference proceedings for which the studies are mostly conducted in academic facilities and institutions.

According to Diment et al and Tack et al, the keyword search strategy is a combination of relevant keywords that were used to collect the studies that included a 3D printing device and a clinical trial. Keywords for this scoping review that will be used to search for the relevant titles and abstracts of publications are very important because they are designed to specify within our context on the usage of 3D printing technology in healthcare. Hence, six keywords (‘three dimensional printing’, ‘3D printing’, ‘additive manufacturing’, ‘rapid prototyping’, ‘patient specific guides’, ‘patient specific implants’) are carefully selected as search terms for searching the relevant titles and abstracts from the electronic databases.

The next step will be to screen each of the studies to identify its affiliation and then to compile those included studies from 10 Southeast Asian countries (Malaysia, Indonesia, Singapore, Thailand, Brunei, Laos, Vietnam, Cambodia, Myanmar and the Philippines) as our scoping review only focuses on the Southeast Asian geographical region. Also, we will focus on the publication that was published during the last 10 years (ie, between the years 2011 and 2021) which could yield a better magnitude of research contribution by the Southeast Asian researchers and authors in 3D printing technology within this stipulated time period. The pilot search strategies for conducting a search in PubMed, CINAHL, Scopus, ProQuest and Web of Science are shown in the online supplemental material 1.

Selecting eligible studies

The flow of information through the different phases starting from identification of records through databases, screening for duplicates, eligibility assessment and then, finally, the inclusion of relevant literature will be illustrated in a flow chart (figure 1), according to PRISMA. The original flow diagram proposed by the Quality of Reporting of Meta-analyses has been modified to PRISMA to depict the numbers of identified records, excluded publications and, finally, included studies. This high-quality flow diagram can assist readers or reviewers to determine the logical steps of the whole process apart from describing the limit of the process.

In any systematic review, the inclusion and exclusion of studies shall define the extent and integrity of the result, thus the eligibility criteria should be applied liberally at the beginning of the study to ensure that the relevant studies are included, and no study is excluded without a thorough and comprehensive evaluation. Hence, the inclusion criteria that shall be applied in this scoping review are as follows:

- All study designs on 3D printing in healthcare which was conducted in the geographical region of Southeast Asia.
- All studies on 3D printing in healthcare in Southeast Asia.
- Published from the year 2011 to 2021.
- The language is only from the published literature written or translated in English and Malay.
The exclusion criteria in this scoping review are as follows:
- Any existing literature that is not conducted in the geographical region of Southeast Asia.
- Not related to 3D printing in healthcare.

The first stage of the screening process shall consist of a thorough examination of the titles and abstracts to minimise the chance of wasting time and resources on publications that did not fit the minimum inclusion criteria. All records will be doubly evaluated by two reviewers who will work independently to ensure the delivery of the procedure quality. If there is any ambiguity with the study selection, the full text of the article will be discussed to see if it has fulfilled the minimum requirements for inclusion. After identifying and removing all duplicates from the various databases, the titles and abstracts of each publication will be reviewed by two reviewers who will work independently to determine the eligibility for inclusion. Whenever a disagreement between the reviewers arises, the reviewers will carefully reconsider their justifications for either inclusion or exclusion; and where required for clarification, the paper’s relevance, by means of the introduction and methodologies, will be assessed. Consensus on the eligibility will be achieved after a discussion of all papers to reach a mutual consensus between reviewers. Each of the included articles will be subjected to a careful review of its full text, and the references cited in these studies will also be carefully evaluated for their relevance (and their eligibility for inclusion) by using the same inclusion criteria. For any publications that are deemed relevant to the topic that could not be procured through the databases, attempts will be made by engaging with the authors via email or contacting the journal publishers to obtain full-text copies of selected articles.

**Charting the data**

A data charting table will be provided to tabulate the results of the following items from all included studies in this scoping review, namely type of publication, country, author(s), title, abstract, aim, study design, types of products, 3D printing technology, materials used in 3D printing, medical category, the scope of research and the outcomes of each study. This will be used to capture germane information from each included study electronically. The indication for each of the descriptions of the suitably extracted information or item is listed in table 1.

Based on table 1, the items for data extraction shall depict the information required to provide evidence about the 3D printing technology in the Southeast Asian countries, which are Malaysia, Thailand, Singapore, Indonesia, Philippines, Brunei, Laos, Vietnam, Cambodia and Myanmar. The publication retrieved will mostly cover, from the original research article (research involves in vitro, in vivo or human studies), systematic review articles (eg, meta-analysis, narrative review, rapid review) and case reports. The aim of the selected studies should also portray a significant magnitude of 3D printing towards clinical improvements in medical treatment. Next, the study design is one of the essential aspects of clinical research as it determines the scientific integrity of the study and the credibility of the data from the study. However, the quality of each study will not be evaluated as part of this scoping review as we intend to merely explore the general scope of research in 3D printing technology.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Indication for each item in the data extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Item</strong></td>
<td><strong>Description</strong></td>
</tr>
<tr>
<td>Type of publication</td>
<td>All settings are accepted (original research articles, systematic review articles, case report, grey literature).</td>
</tr>
<tr>
<td>Country</td>
<td>Eligible countries: 10 Southeast Asian countries (Malaysia, Thailand, Singapore, Indonesia, Philippines, Brunei, Laos, Vietnam, Cambodia, Myanmar).</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Author(s) affiliated and not affiliated from 10 Southeast Asian countries.</td>
</tr>
<tr>
<td>Title and abstract</td>
<td>Keywords containing ‘three dimensional printing’, ‘3D printing’, ‘additive manufacturing’, ‘rapid prototyping’, ‘patient specific guides’ and ‘patient specific implants’.</td>
</tr>
<tr>
<td>Aim</td>
<td>Objectives of the published literature related to 3D printing towards patients in a clinical setting.</td>
</tr>
<tr>
<td>Study design</td>
<td>Any study design (descriptive or analytical; eg, cross-sectional, case–control, randomised controlled trial).</td>
</tr>
<tr>
<td>Type of product</td>
<td>Proof of concept, prototype or established device (eg, preoperative planning, devices to aid surgery, therapeutic devices).</td>
</tr>
<tr>
<td>3D printing technology</td>
<td>Types of technology used in 3D printing (eg, stereolithography (SLA), fused deposition modelling (FDM), selective laser sintering (SLS)).</td>
</tr>
<tr>
<td>Materials</td>
<td>Type of materials used to design 3D printing layering (eg, nylon, resins, graphite).</td>
</tr>
<tr>
<td>Medical category</td>
<td>Any medical field that uses 3D printing (eg, dental, orthopaedics, paediatrics).</td>
</tr>
<tr>
<td>Scope of research</td>
<td>The focus of the research (eg, hand prostheses, gait analysis, drug delivery system).</td>
</tr>
<tr>
<td>Outcomes</td>
<td>Any findings related to the prevalence, cost, effectiveness, advantages, disadvantages and future improvement.</td>
</tr>
</tbody>
</table>
hence we ought to exclude it as one of the items in the data charting for our scoping review. For the purpose of retrieving detailed information on 3D printing technology, the extracted information will comprise the type of product and technology. In this scoping review, we intend to identify any established 3D printing devices or prototypes used in the healthcare sector by countries within the Southeast Asian region apart from the types of technology which have been established by the American Society for Testing and Materials for the 3D printing technology catalogues, namely directed energy deposition, binding jetting, material extrusion, powdered bed fusion, material jetting, sheet lamination and vat photopolymerisation. Also, we aim to investigate the trend of usage regarding the kinds of products and technology used by the countries. Furthermore, information on the usage of 3D printing in various medical branches also will be categorised along with the scope of research to discover the most medical branch that used the resplendent advancement of 3D printing. Lastly, we figure that the outcome from each study is the most important item in our data charting because we could potentially recognise the effectiveness, advantages and disadvantages along with the future improvements towards the patients as we can meaningfully deduce the impactful definition of 3D printing in healthcare within the region. Thus, the detail on each of the items is important to retrieve a comprehensive scoping review for discussion.

Collating, summarising and reporting the results

This scoping review focuses on the overview of the research rather than the assessment of the quality of the studies, since a scoping review involves the synthesis and analysis of a multitude of research and non-research sources to offer an improved conceptual clarity regarding a specific topic or field of evidence. Therefore, in order to draw conclusions from all data collated within each category, it is first necessary to identify multiple articles stemming from a single topic, which will then be grouped and treated as a single unit of analysis. The results gathered from this scoping review will be synthesised and reported to describe the findings of the focus and direction, types of research and establishment of the difference of 3D printing in healthcare research among Southeast Asian countries. Further developments can then be achieved from this scoping review and perhaps a related systematic review will finally be developed. The findings from this scoping review will give numerous benefits to all countries in Southeast Asia, including Malaysia, to improve the potential of 3D printing technology within the realms of the local healthcare sector. Limitations and research gaps from this scoping review also will be examined to put forward a better understanding and perception of the potential for 3D printing technology in the healthcare industry of the entire Southeast Asian region.

Patient and public involvement

No patient was involved.

ETHICS AND DISSEMINATION

The scoping review protocol is initially developed to provide the overall strategy for the development of the scoping review before the actual review process is started. The protocol consists of a detailed and structured plan along with the objectives and methodology of the scoping review. Hence, the results of this scoping review will illustrate an overview of the 3D printing in healthcare among Southeast Asian countries which can be a useful guide for the advancement which can be accentuated in future research. It also can be an informative notion for the various stakeholders such as researchers, public health agencies and government delegations to fathom the potential of 3D printing advancement within the healthcare sector for the benefit of Southeast Asian countries including Malaysia in the future. Any modifications that become necessary to be made to the protocol will be documented with such amendments in the scoping review findings by the research team. For the purpose of research dissemination, the full report of the findings of this scoping review will be submitted for publication in a scientific journal.

The study has been registered under the National Medical Research Register (NMRR) Malaysia (NMRR ID-21-02415-UMN). However, it is not necessary to obtain ethical clearance for this study since this scoping review methodology does not involve the participation of human subjects and only requires reviewing and data collection from the existing literature. Thus, a waiver of consent has been approved by the Medical Research and Ethics Committee Malaysia for this study.

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Contributors All authors discussed the protocol design, development of the research question and study methodology. WHL and PMC supervised and validated the study. MNN, MLL, YKH and LLT wrote the first and subsequent drafts of the manuscript. All authors contributed to the manuscript revision, and read and approved the submitted version.

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Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

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REFERENCES


