Healthcare - China

A Primer on AI in China Healthcare: From Concept to Applications

Primer

Bank of America Merrill Lynch

Equity | 27 May 2019

Fast development of AI technology making it a reality

A machine is said to have AI when it has the cognitive ability to perform functions such as perceiving, learning and reasoning in a similar way to the human brain. Over the past decade, fast development of hardware and algorithms and availability of very large datasets have enabled many key AI applications in our everyday-life; AI is no longer just the domain of scenes in sci-fi movies. Currently many AI applications belong to machine learning and deep learning, here, we introduce their basic concepts and principles.

High demand for AI in healthcare and market size gauge

Aging population, a lack of high quality medical resources, and fast-rising public healthcare expenditures present challenges to the China government and its public healthcare fund. The government has been supportive on AI development by issuing multiple policies and guidance. It is estimated by Accenture and a few market research groups that worldwide AI in healthcare market size could reach US$ 5-6B with a CAGR of 40-50% in three years. Although AI R&D in healthcare in China started a little later than in developed countries, investment in the field has reached more than 1 billion RMB annually and the number of start-ups has grown fast.

Public companies and start-ups actively developing AI in healthcare in China

AI technology has many important applications in healthcare. We review AI applications in medical imaging, robot-assisted surgery, drug R&D, virtual hospital assistant, personal health management, expenditure monitoring of Medical Fund, and commercial healthcare insurance operation. For most of applications, we present case studies and a list of Chinese start-ups developing that application. Given the importance of AI in China healthcare, Internet giants, mid-size public companies, and private start-up companies in China have invested significantly to develop AI based healthcare solutions. We believe at a macro level, future development of AI in China healthcare could be characterized by: 1) target data incompleteness and inconsistency; 2) lack of over-concentration in just a few sub-sectors; 3) developments in AI applications in both diagnosis and treatment; 4) identification of more business models; 5) new industry standards for AI products; 6) more expertise with both AI and medicine backgrounds; and 7) pursuit of more fundamental R&D for AI in healthcare.

We will host a panel “AI in China Healthcare” on Monday

On May. 27 we will host a panel on “AI in China Healthcare” at our Innovative Conference in Shenzhen. The CEO of Insilico, COO of United Imaging and a professor from the Chinese Academy of Science will attend to discuss issues and prospects for AI in China healthcare.

China
Healthcare

Yang Huang, CFA >>
Research Analyst
Merrill Lynch (Hong Kong)
+852 3508 3945
yang.huang@baml.com

Qi Wen, CFA >>
Research Analyst
Merrill Lynch (Hong Kong)
+852 3508 3996
qi.wen@baml.com

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Introduction to artificial intelligence (AI)

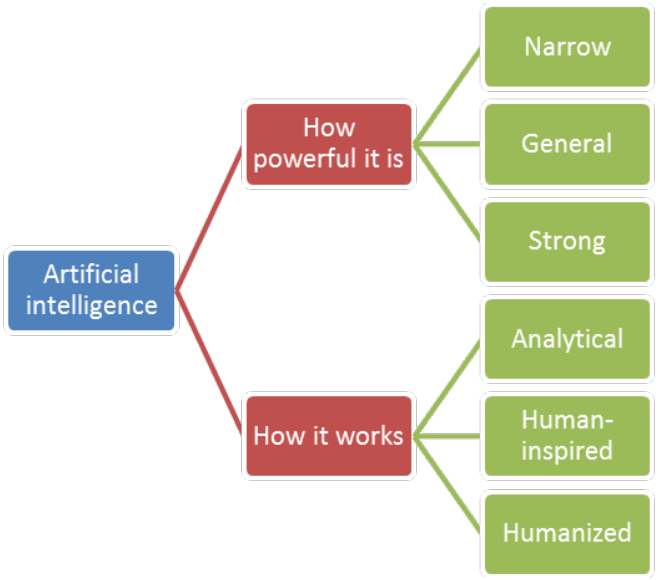
What is AI?

AI may be one of the trendiest words found in almost every industry in recent years. However, AI is not a young term coined in the 21st century as some people may think and has a long history. Actually, the concept of AI was first proposed in 1956 by a group of intelligent experts with different backgrounds. Though the concept of AI has continued to evolve in the last a few decades, its central meaning appears to be intact. Simply put, a machine (more concretely, a computer software/system) is said to have AI when it has the cognitive ability to perform functions such as perceiving, learning and reasoning in a similar way to the human brain.

Specifically, the intelligence an AI system can be divided into three levels based on how powerful it is: 1) narrow, 2) general and 3) strong. A narrow-level AI can perform particular tasks (in a relatively narrow application field) better than humans. We are currently in this level of AI development. If an AI is able to perform any tasks with the same accuracy as humans, it is then deemed as general AI. A strong AI can return better results in many tasks than humans. For example, Alpha Go beat the world champion in the board game Go or *Weiqi*. If one day Alpha Go or another system can beat any human in any game, we might consider it has strong AI.

AI can also be classified by how it works: analytical, human-inspired and humanized AI. Analytical AI learns from past experience to generate guidance for future decisions. Human-inspired AI can understand human emotions and incorporate them in its decision-making process. Humanized AI, acting like a human, has self-consciousness and self-awareness.

Exhibit 1: Classification of AI



Source: BofA Merrill Lynch Global Research

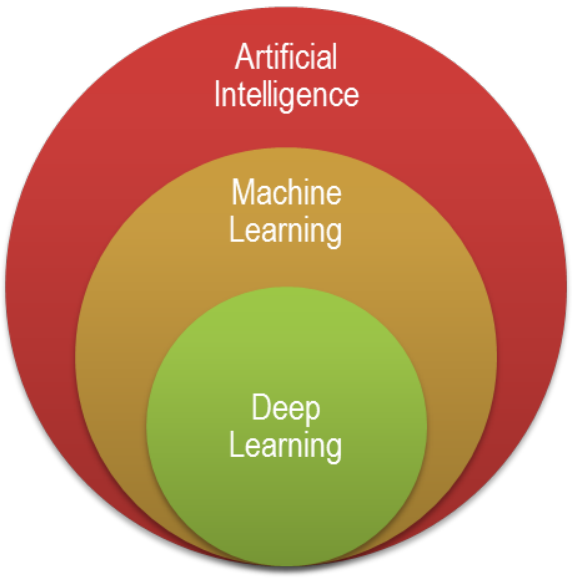
Many AI applications are based on machine learning

AI is a broad concept with subfields such as machine learning and symbolic reasoning. Currently it seems that machine learning (ML) is the mainstream of AI research. ML is powered by algorithms, a field of study that gives computers the ability to learn without being explicitly programmed. ML can be separated into supervised and unsupervised ML. Supervised ML is first "trained" with pre-defined data sets (that contain both inputs and the desired outputs) before it can reach accurate conclusions on new data. Unsupervised

ML (i.e., data mining) can by itself find patterns and relationships among data (contain only inputs).

Deep learning is a sub-field of machine learning and uses different layers of artificial neural network (ANN) to learn from data. The structure of multiple layers is an imitation of biological neural networks in processing and distributing information. An example of deep learning is Google LeNet that contains 22 layers. In recent years, as there are much more computing power and training data, deep learning has gleaned a lot of attention and made quite a few breakthroughs.

Exhibit 2: The scope of AI with machine learning as a key part of AI



Source: BofA Merrill Lynch Global Research

Strong growth in AI R&D depends on three elements

The concept of AI has been raised for decades. But it is those recent breakthroughs in several underlying basic areas, namely hardware, data and algorithm, which significantly facilitate AI developments.

Hardware. Traditional CPUs, even after the explosion of computing capabilities, are only able to support small deep-learning models. Because of the developments of GPU (graphics processing unit) or other specifically designed hardware, such as Google's Tensor Processing Unit (TPU), whose parallel structure can process large blocks of data in parallel, computing infrastructure and architecture have risen to support more powerful AI systems.

Data. Data are blood for AI. We are living in a world that accumulates a tremendously large amount of data every day, providing groundwork for AI to grow. It was estimated that there are 2.5 quintillion (10^18) bytes of data created each day at our current pace. And technology advancements in data storage allow people to store a large amount of data in an easier and more efficient way. Cloud services provided by companies such as Amazon, Microsoft and Alibaba have successfully transformed the way we store and analyze data with speed and privacy. However, most of data are generated in an unstructured way and they often need to be converted to structured data to be used by computers.

Algorithm. Algorithm provides humans a necessary tool to tell computer to perform functions that can't be hard coded. With powerful hardware and enough amounts of data, algorithm can then be put in place to drive AI applications.

Machine learning

Machine learning is based on mathematical models that algorithm build with training data without being explicitly programmed. As the basis and core of developing machine learning, the mathematical model start with data with only a few dimensions (i.e., a commonly-seen three-dimension data set) and simple predictor functions with coefficients. A simplest example of a predictor function will be as follows, where x is one point of an input data set X and has an output value associate with x. h(x) is the output computed from the model and we want it to be close to the actual output corresponding to data point x. For example, if this is a binary classification task, output can take value 0 or 1. Then the task of a training algorithm is to determine two coefficients θ_0 and θ_1 so that h(x) can best approximate output for the whole input set X, i.e. to minimize an error function to measure how good the approximation h(x) reaches.

$$h(x) = \theta_0 + \theta_1 x$$

A more complicated version of the above function would include more dimensions. For example, the following model is for an input data set on a 4-dimersion space, has 6 coefficients to be determined, and contains non-linear terms such as x square. If again we are using the model for a binary classification problem, we can think of the task as to find a hyper-plane in that 4-dimension space to separate input data set X into two parts. Ideally, we want to find a hyper-plane (determine all coefficients) so that input data points on one side of that hyper-plane all have output 0 and input data points on the other side of that hyper-plane all output 1.

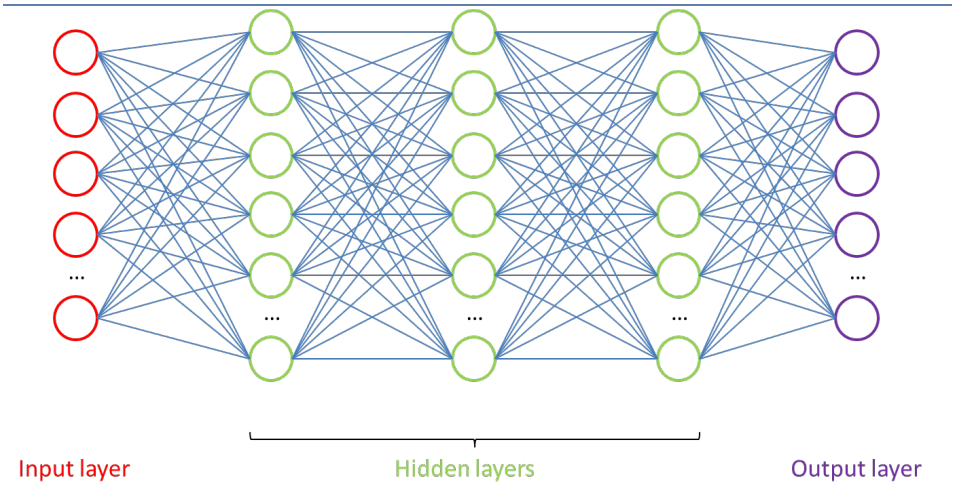
$$h(x_1, x_2, x_3, x_4) = \theta_0 + \theta_1 x_1 + \theta_2 x_3^2 + \theta_3 x_3 x_4 + \theta_4 x_1^3 x_2^2 + \theta_5 x_2 x_3^4 x_4^2$$

In order to deal with real-world problems, mathematical models used in machine learning are way more sophisticated and can include millions of dimensions and complex predictor functions with hundreds of coefficients.

Deep learning

Deep learning is based on a deep neural network (DNN), essentially an artificial neural network with multiple layers between inputs and output layers. The basic element of an artificial neural network is a neuron (a circle in the following chart). A neuron is a computing element with an input, an output and an internal function. The internal function will calculate an output at time t+1 according to input at time t, neuron state at time t, and a fixed threshold which can be changed by a training algorithm. DNN architectures generate compositional models where each input can be expressed as a layered composition of primitives (if an input is an image, a primitive can be a pixel). The extra layers enable composition of features from lower layers, potentially modeling complex data with fewer neurons than a similarly performing shallow network.

Exhibit 3: General structure of DNN



Source: BofA Merrill Lynch Global Research

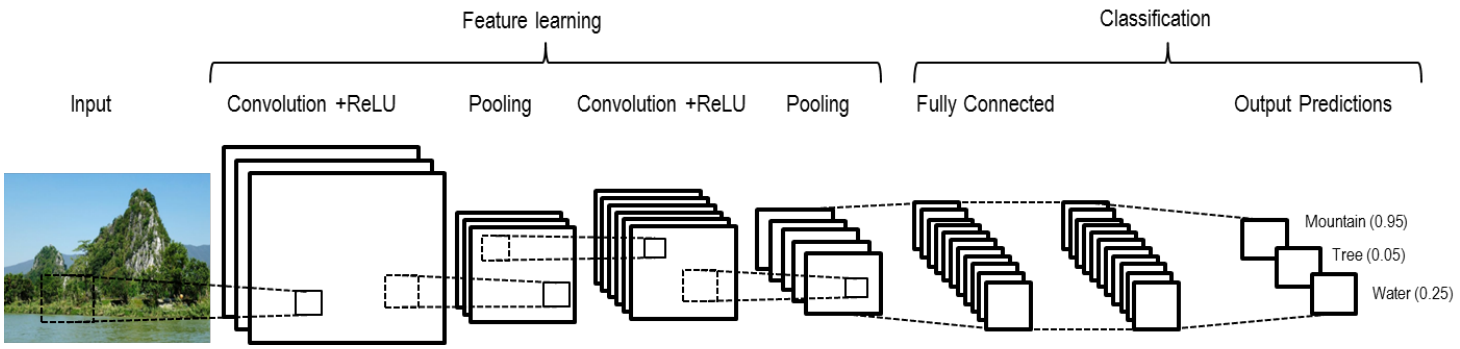
The learning process of a DNN has two phases in general: 1), applying a nonlinear transformation of input and create a statistical model as output; 2), improving the model. Neural networks will iterate the two phases until a model with acceptable accuracy is generated.

Convolutional neural networks (CNN).

CNN is sub-type of DNN that is being widely used to analyze visual images. For example, a well-known toy application of CNN is to determine whether a picture has a cat or a dog. Its work process can be simply summarized as the follow:

- CNN is given an image (pixels for the network) which is processed in the input layer
- CNN identifies unique features during the feature learning phase via hidden layers. This often involves convolution (application of filters onto input), activation (application of threshold that we mentioned when discussing neuron), and pooling (downsampling to provide variance) to generate feature maps
- Using a fully connected neural network, CNN predicts outcomes with the highest probability based on its knowledge of the image. By "fully connected", we mean to flatten the output of the last convolution layer and add more layers so that every neuron of the current layer is connected with every node of the next layer.

Exhibit 4: General process of CNN application in visual images



Source: BofA Merrill Lynch Global Research

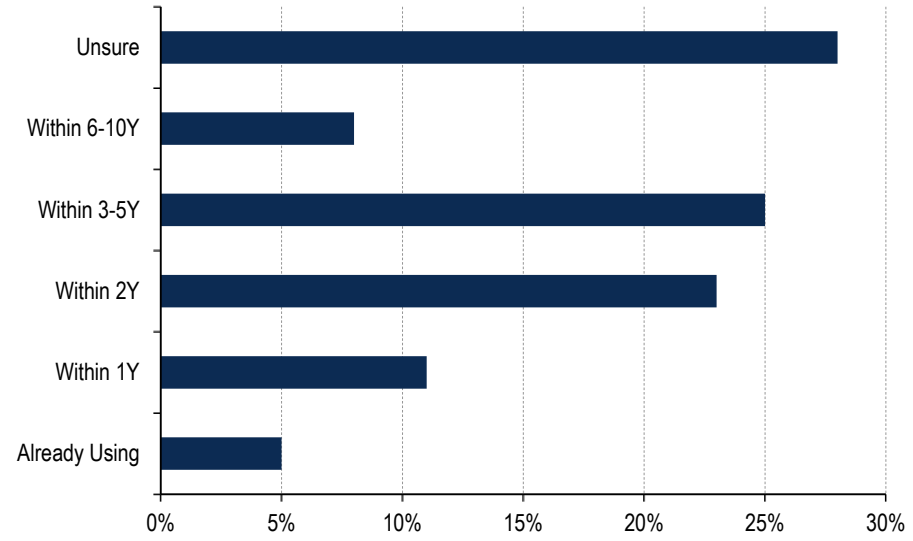
Global development of AI in healthcare

Healthcare has high demand for AI applications

The global aging population, the need for healthcare services and products and the mounting financial burden on healthcare system have all contributed to the increasing needs to improve efficiency of healthcare industry. Boosted by the growth of capabilities in computational hardware and development in algorithm, AI is demonstrating promising applications in many areas in healthcare industry, some of which have been consuming a large amount of human and financial resources in the industry. Though still in a very early stage of business life-cycle, AI-powered healthcare start-ups are developing ways to innovate and change the traditional approaches rooted in the industry.

Driven by the big potentials of AI in healthcare, some healthcare stakeholders are acting. A 2017 HIMSS Analytics survey shows that around 35% of healthcare organizations plan to apply AI within 2 years, and half intend to do so in 5 years. Today, less than 5% are already using AI.

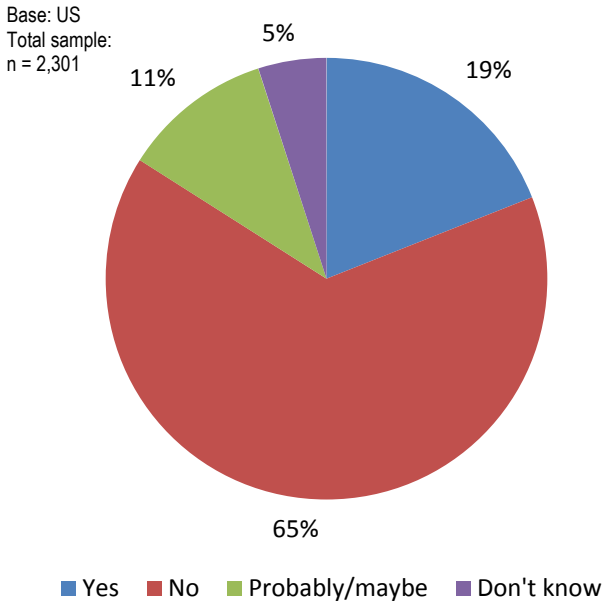
Chart 1: Question: When do you expect your organization to leverage AI?



Source: HIMSS Analytics

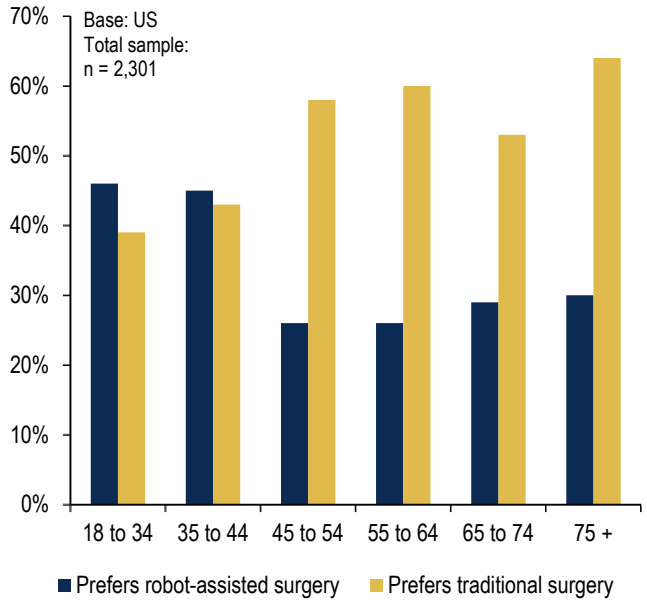
Consistent with the above survey that only a small number of healthcare organizations are applying AI technology, many patients have not experienced AI based healthcare. In particular, older generations appear to need more education to adopt AI based healthcare. Accenture found that, as a relatively new field, AI + healthcare has not been experienced by most patients in US. In terms of choosing robot-assisted or traditional surgery, older people are more reluctant to accept the new technology than younger people.

Chart 2: Question: Have you ever interacted with any AI technology that relates to your health?



Source: Accenture

Chart 3: Choice of robot-assisted or traditional surgery, by age group

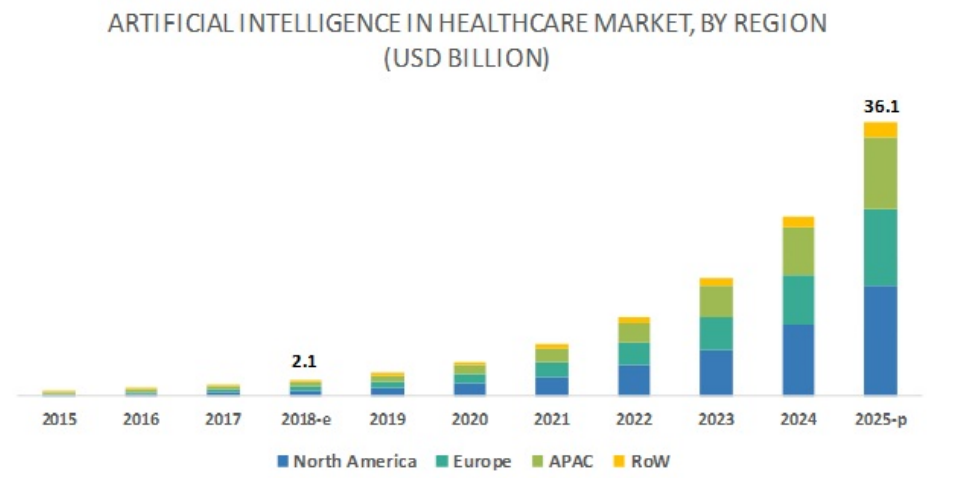


Source: Accenture

Global market of AI healthcare expected to grow very fast

Some AI market research report estimated that the AI healthcare market is expected to grow from USD 2.1 billion in 2018 to USD 36.1 billion by 2025, at a CAGR of 50% during the forecast period. Accenture made a similar forecast and estimated the global AI health market to reach $6.6 billion by 2021 with a CAGR of 40%. The increasing amount of medical data are setting a firm ground for AI development and the urgency of reducing financial burden of healthcare system in many regions is driving the growth of the market. Improved computing power and declining hardware cost are other key drivers in the market.

Exhibit 5: AI in healthcare market is expected to grow at a CAGR of 50%

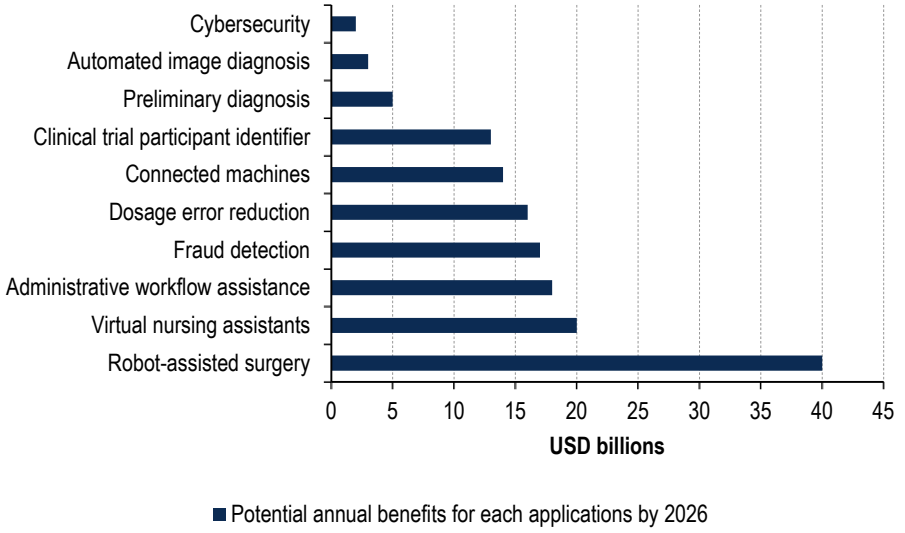


Source: Markets and Markets

Accenture provides another perspective to gauge the size of AI in the healthcare market: potential annual benefits (potential annual savings by applying AI in 2026). It estimated that a total of $150 billion potential annual benefits could be brought by AI to

healthcare industry by 2026. Robot-assisted surgery ranks No. 1 among various AI applications in terms of the amount of annual benefits it can bring.

Chart 4: Potential annual benefits for each applications by 2026

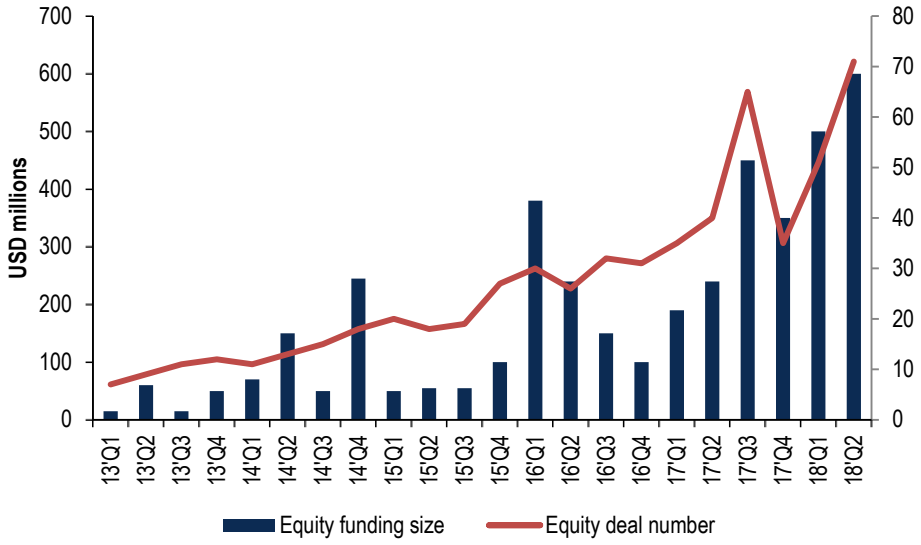


Source: Accenture,

Investment into AI based healthcare also grows fast

Everest Group, a consulting company, predicts that investments in AI in healthcare will grow from US$1.5 billion in 2017 to exceed US$6 billion by 2020, representing a CAGR of 34%. Data compiled by CB Insights show that the size of total fund raised and the number of deals in AI in healthcare in the US have been increasing since 2013 and have reached a historic high in 2018, indicating the growing attractiveness of AI based on healthcare.

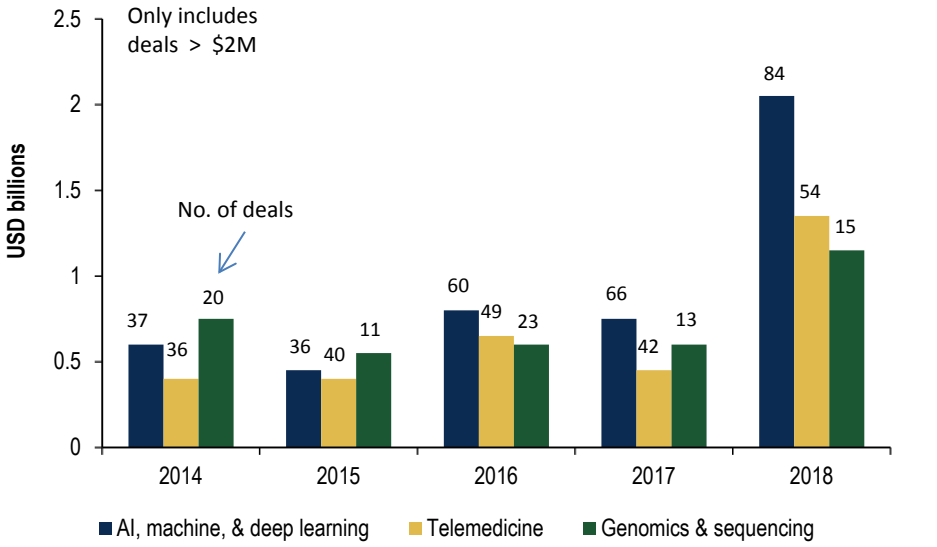
Chart 5: U.S. equity funding of AI in healthcare is on an upward trend



Source: CB Insights

Compared with other popular digital tools in healthcare field, AI has been gaining most preferences from capital market in recent years, indicating capital market's high confidence in the future of AI in healthcare.

Chart 6: Capital prefers AI related investments in U.S. market



Source: Rock Health, BofA Merrill Lynch Global Research

Major participants in AI in healthcare

Three types of players are betting big in AI in healthcare: start-ups, internet giants, and traditional medical device manufacturers. Start-ups have limited financial resources but are more sensitive to industrial trends and often are biggest innovators in the field. Start-ups generally focus on exploring opportunities in the business-end. Internet giants, such as Google, Tencent and Alibaba, are trying to leverage their role as the core traffic portals as well as their leading cloud technology to reach more healthcare stakeholders. Examples are Google AI and Alibaba's ET Brain. Traditional medical devices manufacturers, such as Philips, GE, Siemens, are working hard to cross-sell their AI products/services to their existing customers of medical devices.

The technology of all three types of participants has unique advantages. Compared with start-ups and Internet companies, medical devices companies know healthcare industry well and possess valuable clinical data generated from hardware. Start-ups can nevertheless be more sensitive to market trend and act quickly on it. Internet giants have the best talent resources in AI, which is a core asset in AI development. In addition, internet giants, due to their large number of users, potentially see more application scenarios to explore how AI can improve healthcare

AI in China and policy support from China governments:

What can AI do specifically for China healthcare?

Similar to the situations seen around the world, aging population, lack of high quality medical resources, and fast-rising public healthcare expenditures are also presenting various challenges to China government. Interestingly, China also owns some critical characteristics that favor the growth of AI in healthcare. As the country with the largest population in the world, China has accumulated massive amount of medical data and that data growth is likely to accelerate as China government improves healthcare standards for increasingly large population. Philips (China) estimates that 20% of medical data in the world will be stored in China by 2020. The huge amount of medical data will provide a firm base for any participants of AI in healthcare in China.

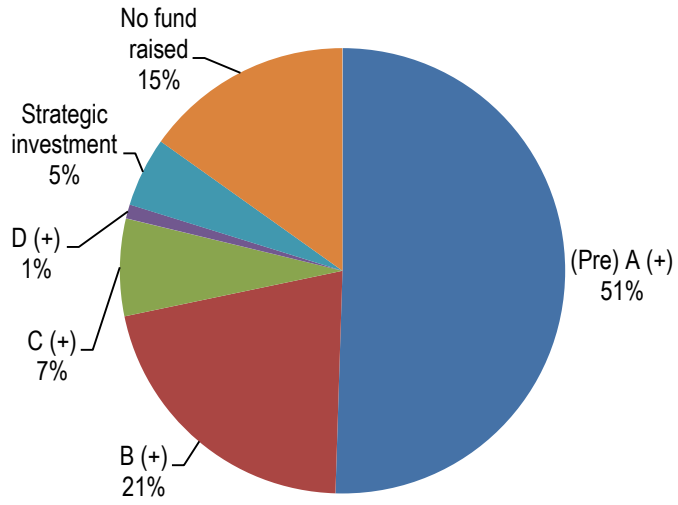
In addition, China starts to own a comprehensive and improving computing infrastructure. Private sector has seen booming developments in computing power. Ali Could and Tencent Cloud are growing into large scale service providers in domestic and international market.

Though China is still a developing country, high proportion of aging population, which is typically seen in developed countries, starts to emerge in China. Burdens on the country's healthcare system will continue to increase if no proper actions are taken in a timely manner. Noticing the big potential of AI in healthcare, the China government publishes a series of favorable policies to promote AI application in the healthcare field. The AI technology has officially been raised to a nationally strategic level.

China AI healthcare startups are well funded

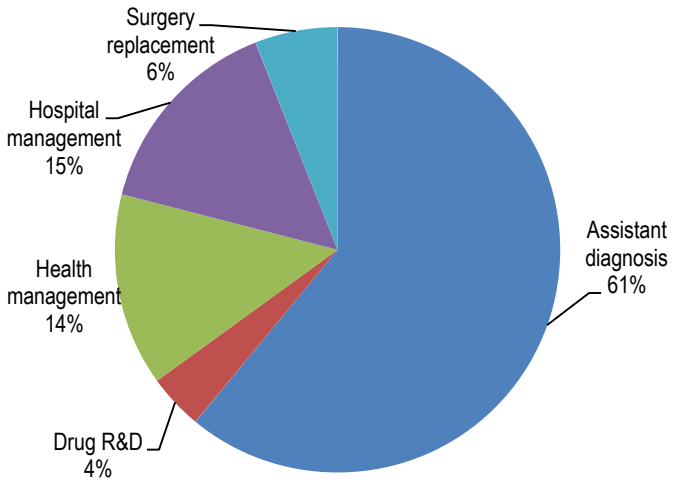
According to Health Point, a healthcare media, as of June 2018, 89 AI-in-healthcare start-ups in China have raised a total of RMB 22 billion in various rounds. Health Point found that most start-ups were still at early stage (A-round) while most of them focus on assistant diagnosis, which mainly includes medical imaging and voice identification. IDC forecasts smaller financing size for AI in healthcare in China, but the figure will reach ~RMB 2 billion by 2022, representing a growth rate of 71.8% from 2017 through 2022.

Chart 7: Most Chinese start-ups are in early stage of development



Source: Health Point

Chart 8: Competition is intense in assistant diagnosis; big potentials in other applications



Source: Health Point

China government providing strong support for AI R&D

China government has been putting efforts to develop domestic AI industry in recent years. A series of policies and guidelines are issued by government agencies including the State Council and multiple national-level ministries. We expect the China government to continue to support AI development in the foreseeable future and more favorable policies could further advance the growth of AI related products and services.

Table 1: Policies regarding to developments of artificial intelligence in China

Date	Issuing agency	Type	Document
May-15	State Council	Notification	State Council notification on the issuance of Made in China 2025
Jul-15	State Council	Advice	State Council advice on actively carry forward the movement of Internet +
Mar-16	State Council	Plan	Outline of the 13th Five-Year Plan on domestic economy and social developments
Apr-16	Ministry of Industry and Information Technology (MIIT), National Development and Reform Commission (NDRC), Ministry of Finance	Plan	Development plan of robot industry (2016 - 2020)
May-16	NDRC, Ministry of Science and Technology, MIIT, Cyberspace Administration of China	Plan	Execution plan of AI three-year plan of Internet +
Jul-16	State Council	Plan	13th Five-Year Plan of national science and technology innovation program
Sep-16	NDRC	Notification	Notification on the application innovation programs of Internet +
Sep-16	MIIT, NDRC	Movement	Special movement on the innovation of intelligent hardware industry (2016 - 2018)
Dec-16	State Council	Plan	13th Five-Year Plan on the national development of strategic, emerging industries
Jan-17	General Office of the State Council	Advice	Advice on boosting healthy developments of internet industry
Mar-17	State Council	Report	Government Work Report
Jul-17	State Council	Plan	Development plan on new generation artificial intelligence
Oct-17		Report	19th CPC National Congress report
Dec-17	MITT	Plan	Three-year movement plan on boosting the development of new generation artificial intelligence industry
Mar-18	State Council	Report	Government Work Report
Apr-18	Ministry of Education	Plan	Movement plan of higher education institutes on artificial intelligence
Apr-18	State Council	Advice	Advice on boosting the development of Internet + Healthcare
Nov-18	MIIT	Plan	Application and recommendation plan on new generation artificial intelligence
Mar-19	Central committee of comprehensive and deepening reformation	Advice	Advice on boosting the deep integration of artificial intelligence and real economy
Mar-19	State Council	Report	Government Work Report

Source: China Government websites, BofA Merrill Lynch Global Research

China internet giants in AI in healthcare

Big Chinese internet companies such as BAT (Baidu, Alibaba, and Tencent) are investing big in AI in healthcare. Tencent considers healthcare as a core part in its AI plan. The company launches Miying, a diagnostic medical imaging service, Ruizhi, an AI engine for service guidance in hospital, and Super Brain, a powerful tool integrating functions in drug R&D, gene analysis, disease screening, hospital management, etc. It appears that Tencent is building a big eco-system for AI in healthcare.

Alibaba, via Ali Health, develops an AI medical platform, called Doctor You, which focuses on research and diagnosis, assistant examination and physician training. Ali Cloud introduces ET Medical Brain to provide services for many medical scenarios such as medical imaging, assistant diagnosis, and medical resource optimization.

Baidu developed Baidu Lingyi, which has been applied medical triage, hospital service guidance, screening for eye diseases, and clinical decision supporting system.

Other Chinese public companies also investing in AI in healthcare

In addition to internet giants BAT that are positioning themselves in AI in healthcare, some other public Chinese companies, including PingAn Good Doctor, Ali Health, and iFlyTek, are also developing AI applications in healthcare.

PingAn Good Doctor is a leading healthcare service provider in China with expertise in family doctors, consumable medical services and health management. As a comprehensive healthcare platform covering online and offline services, Good Doctor has considered AI as a core technology since its inception. The platform's largest business segment, family doctor, strategically combines AI with physicians to provide various assistant diagnosis services such as online consulting, appointment, follow-up diagnosis. Its AI assistant diagnosis system has a knowledge base covering more than 3,000 diseases and has accumulated 410 million records with 35,000 disease labels, which provide a large amount of high quality data to optimize AI algorithms. As of December 2018, the AI system is applied in all departments of its in-house medical team and is used by more than 100 external hospitals.

Ali Health is acting as a flagship platform in Alibaba's "Double H" strategy (health and happiness) in healthcare industry. The platform provides a unified online-to-offline solution to improve efficiency in healthcare resource allocation by leverage Alibaba's advantages in e-commerce, cloud computing and logistics. Its business spectrum covers intelligent healthcare, "internet+" healthcare, medical e-commerce and consumable medical services. Ali Health launches China's first commercialized AI-powered medical imaging system in lung disease identification. The company operates an open-source AI platform to provide AI-based applications and services to physicians and researchers in China's top medical institutes. This AI platform, along with Alibaba's other AI related medical products, constitute the medical part of ET Brain 2.0, a comprehensive AI network introduced by Ali Cloud.

As the leading Chinese company in voice identification, iFlyTek has applied AI in its products to support doctors in several medical scenarios including medical record generation, medical imaging and assistant diagnosis system. As of December 2018, AI-based voice identification products are installed in multiple China's top medical institutes and provide 600,000 times of services per month. 905 hospitals gained access to its medical imaging identification service which has analyzed 310,000 CT images. Its assistant diagnosis system has been adopted by over 1,000 low-tier healthcare institutes and covered 95% commonly-seen diseases.

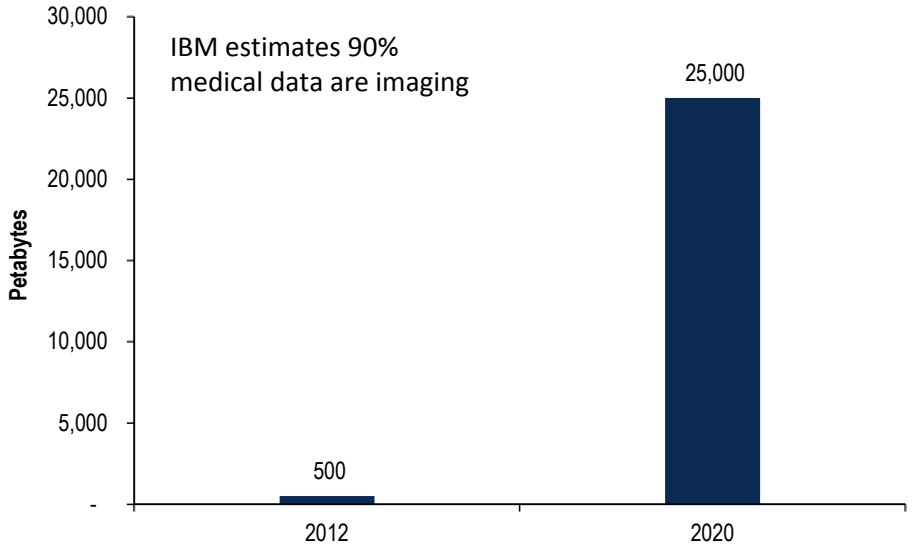
Major applications of AI in healthcare

Among the seven major applications we will discuss later, precision surgery requires the combination between software and hardware, while drug R&D needs advanced research in life science, giving both scenarios higher entrance barrier than the rest. Because of the high volume of data generated in day to day work and relatively standardized data format, medical imaging has grown into an attractive market for AI in healthcare with significant market size. The majority of Chinese AI healthcare companies (especially start-ups) are competing in this field. To help better understand each type of applications, we will discuss one or two representative companies in each application.

Medical imaging

Rock Health expects data in healthcare to grow from 500 petabytes in 2012 to 25,000 petabytes by 2020. According to IBM, 90% of medical data are imaging data. The potential benefits from dealing with imaging data through a better approach are so huge that many entities have been investing in this area for years. After years' of exploration and development, healthcare industry has seen the widest AI usage in the analysis of medical imaging. Thanks to emerging technology and standardized data format, healthcare industry has recognized "AI+ medical imaging" mode as a critical scenario that is the easiest to break into and the closest to commercialization.

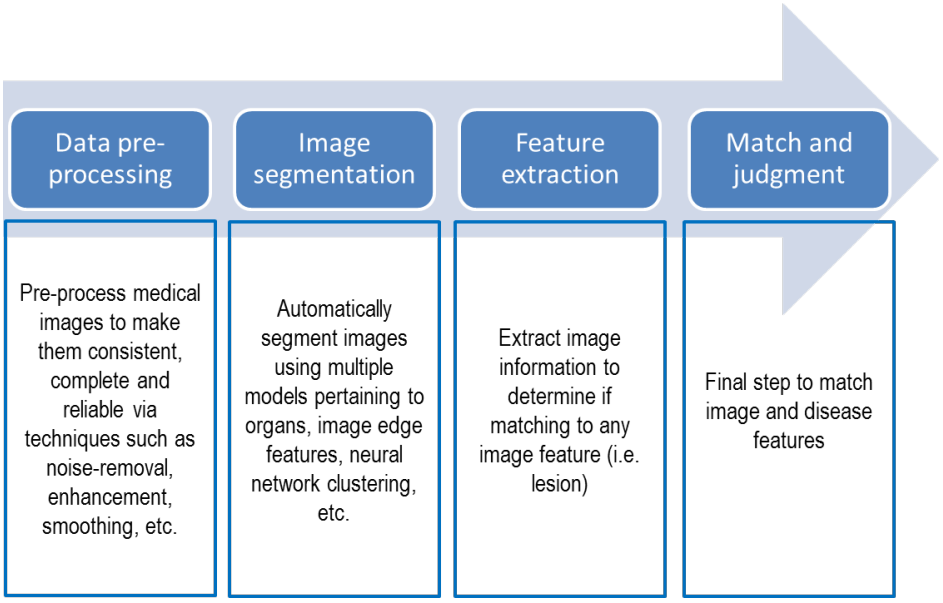
Chart 9: Volume of medical data will grow at exponential pace



Source: Rock Health,

Armed with advanced technology such as deep-learning and improvements in computing infrastructure, AI can significantly boost analysis efficiency and save doctors' time. By "memorizing" , "comparing" and "analogizing" a large amount of medical imaging data (typically after standardization processing), clinical data and research papers, AI can form a sophisticated and deep knowledge system and is capable of processing a large amount of imaging data in various therapeutic areas in a very short time with reliable accuracy (in most cases, greater than 90%). Though physician monitoring is still needed for AI-analyzed imaging, the amount of workload of physicians can be tremendously reduced.

Exhibit 6: General process of applying AI in medical imaging identification



Source: BofA Merrill Lynch Global Research

For example, care.ai, developed by Yitu Tech, a Chinese AI start-up, can complete analyzing a full set of images of a patient with lung cancer in 5 to 10 seconds with an accuracy of above 90%, comparing to 15 to 30 minutes that are typically needed with traditional approaches. Another AI program, Doctor You, developed by Ali Health, finishes analysis of 9,000 lung cancer images in 30 minutes at an above 90% accuracy.

AI can bring more to imaging identification in China

The large unmet medical demand and the imbalanced geographical allocation of medical resources in China have create a market where good physicians have too much workload to handle and less capable physicians also have enough work to do. This makes the improvements in diagnosis accuracy a must in many medical institutes, which creates a huge market potential for AI-supported diagnosis technology.

The difference in diagnosis capabilities among medical institutes and among healthcare practitioners in China has triggered a disproportionate usage (or over-reliance) of device-based diagnosis, of which imaging examination takes the largest proportion. As a result, data volume of medical imaging is growing at a much faster pace than the growth of the number of physicians in radiation departments (CAGR: 30% vs 4.1%) in China.

According to National Health Commission, a total of 1.24 billion radiation scans have been conducted from 2013 to 2015. The 2017 radiation doctor annual meeting of Chinese Medical Doctor Association reported a number of 158,000 radiation practitioners in China, among which approximately 80,000 are radiation doctors. The combined effect translates into an approximate 5,100 radiation images needed to be analyzed per radiation doctor per year. Assume that it takes 10 minutes to analyze an image and a radiation doctor spend 6 hour a day doing the analysis, the work will take about 140 days. If considered the time spent on research tasks, radiation doctor could face intense work burden.

Although the application of AI in medical imaging has already shown significant advantages and efficiency, we believe there are still many uncovered potentials lied within the technology. As the technology and infrastructure continue to evolve, more utility can be extracted soon. IDC forecast AI powered medical imaging technology will soon be deployed in China's first-tier hospitals in next three years. As a result, 20% medical institutes and 40% health science companies are expected to increase productivities by 15%-20%.

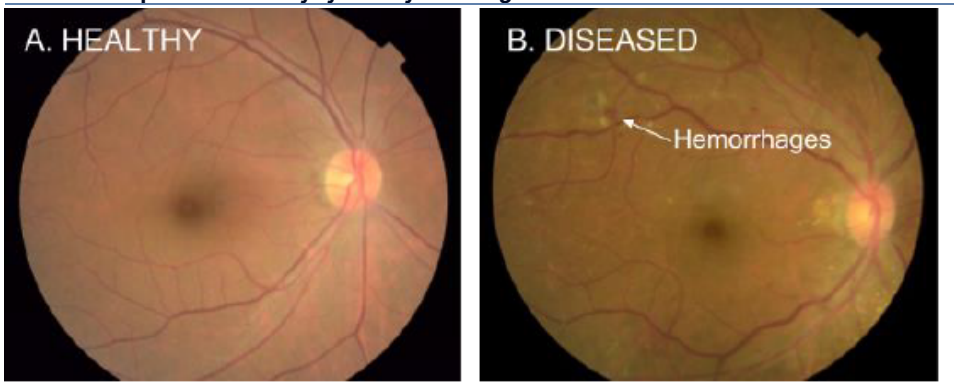
A case study on the diagnosis of diabetic retinopathy (DR).

China has the largest diabetes patient population (110 mn) among a total of 415 mn globally. Without proper treatment, 80% of patients with diabetes will develop DR eventually, which can lead to blindness and significantly reduce life quality. The required regular doctor visits have put a huge workload on ophthalmologists, the number of which is inadequate to meet patient's demand.

Luckily, AI has been shown to be as accurate as humans in DR diagnosis. Google scientists have published research results showing a deep learning algorithm capable of interpreting signs of DR in retinal images. In traditional examinations, doctors look for lesions in the surface of retina, which would be indicative of bleeding and fluid leakage. Google researchers used 128,000 images to train the deep neural network, and then tested its performance on 12,000 images. The deep learning algorithms had comparable performance to ophthalmologist, suggesting the low-cost software solutions could be used to improve care and be rolled out to serve patients.

Accuracy of AI diagnosis highly depends on the quality of data input (eye images in this case). To better apply its technology, Google has teamed up with a J&J's subsidiary to create advanced surgical robotics.

Exhibit 7: Comparison of healthy eye and eye showing DR



Source: Google Research

Why would the application in DR diagnosis be a hot spot among AI start-ups? The risk of being blind due to DR could be reduced by as much as 94% if regular examinations are conducted in the early stage of the disease. However, because of the tiny size of indicative signs in retina and inadequately experienced doctors, misdiagnosis and omitted diagnosis often happen in practice. Given the deep gap between patient demand and medical service supply in China, it is hoped AI technology can mitigate the gap.

DR diagnosis software from Chinese start-ups currently is limited to the stage of examining bleeding and fluid leakage, instead of a true diagnosis. Doctors are still needed to make the final decision on diagnosis, but the time spent on the whole process will be less than 5 minutes. In practices, however, the low image quality (which could be resulted either from improper handling from doctors or the use of different equipment) also raises a major issue for AI application in this area.

United imaging represents how medical device companies apply AI in healthcare

There are quite a few Chinese AI companies working in medical imaging. We believe United Imaging represents a unique direction demonstrating how hardware and AI software can be combined. United imaging combines its rich experience in hardware and AI technology to generate more synergy to customers. The company develops and manufactures a full portfolio of advanced medical imaging equipment, including CT, MI, MR and XR. Data generated from those devices are perfectly compatible with its AI solution.

uClound, the intelligent medical solution developed by the company, provide a comprehensive assists in identifying medical imaging. Its imaging solution contained three intelligent engines in lung cancer, coronary artery (CA), and neural diseases. Based on the deep learning of 210,000 cases from Shanghai, the lung cancer engine can precisely identify smaller size pulmonary nodules and quantify parameters such as nodule size and density with a sensitivity of 95% to early-stage lung cancer, increasing identification rate by 20% for physicians with less than three year experience.

CA engine is able to automatically separate CA images and analyze blood dynamics, which enable the engine to detect ischemia state within CA in the absence of catheter. The neural engine can depict a “high-resolution map” of neuro and functional regions in brain, which can pinpoint lesions from an explicit angel and direct a precise neurosurgery.

Table 2: A sample list of domestic AI start-ups with products/services in medical imaging

Company name	Foundation year	Latest round financing (RMB mn)	Latest valuation (RMB mn)
Qed-tech	2006	> 10 (A)	
Wingspan	2009	> 100 (B)	
United Image	2010	3,333 (A)	33,333
Yitu	2012	> 200 USD mn (C+)	15,000
Medp.ai	2015	> 10 (A+)	

Table 2: A sample list of domestic AI start-ups with products/services in medical imaging

Company name	Foundation year	Latest round financing (RMB mn)	Latest valuation (RMB mn)
Infervision	2015		
12 Sigma	2015	200 (B)	
Huiying Medical	2015	> 100 (B)	
Airdoc	2015	> 100 (B)	
Deep Care	2016	> 100	
Deep Wise	2017	150 (B)	

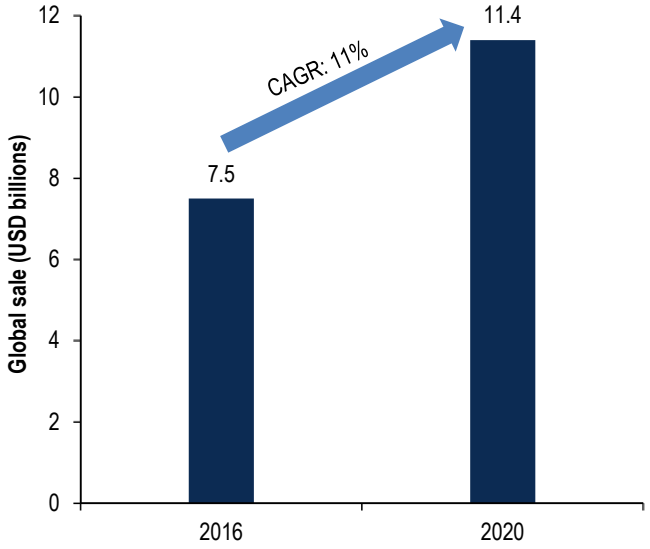
Source: : Company websites, Online news websites such as sohu, BofA Merrill Lynch Global Research

Robot-assisted surgery

Since it began in the 1980s, robot-assister surgery is already a relatively common application in surgery, which is used to overcome the limitations of pre-existing minimally-invasive surgical procedures and to enhance the capabilities of surgeons performing open surgery. Because of the long time and high cost of training an average surgeon, robot becomes a very helpful tool to alleviate the supply gap of good surgeons.

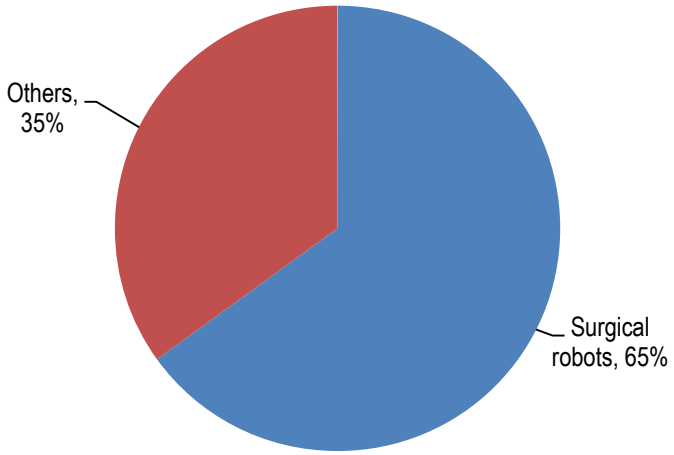
According to Boston Consulting, globally annual sale of medical robots was USD7.5 billion in 2016 and could reach USD11.4 billion in 2020. The consulting firm estimated approximately 4,000 medical robots were sold in 2018 with a CAGR of 34% from 2014 to 2018. Grand View Research, a market research company, estimated surgical robots accounted for 65% of global medical robot market in 2013.

Chart 10: Global sale of medical robots is expected to grow steadily by 2020



Source: Boston Consulting

Chart 11: Surgical robots take the largest share in global medical robot market



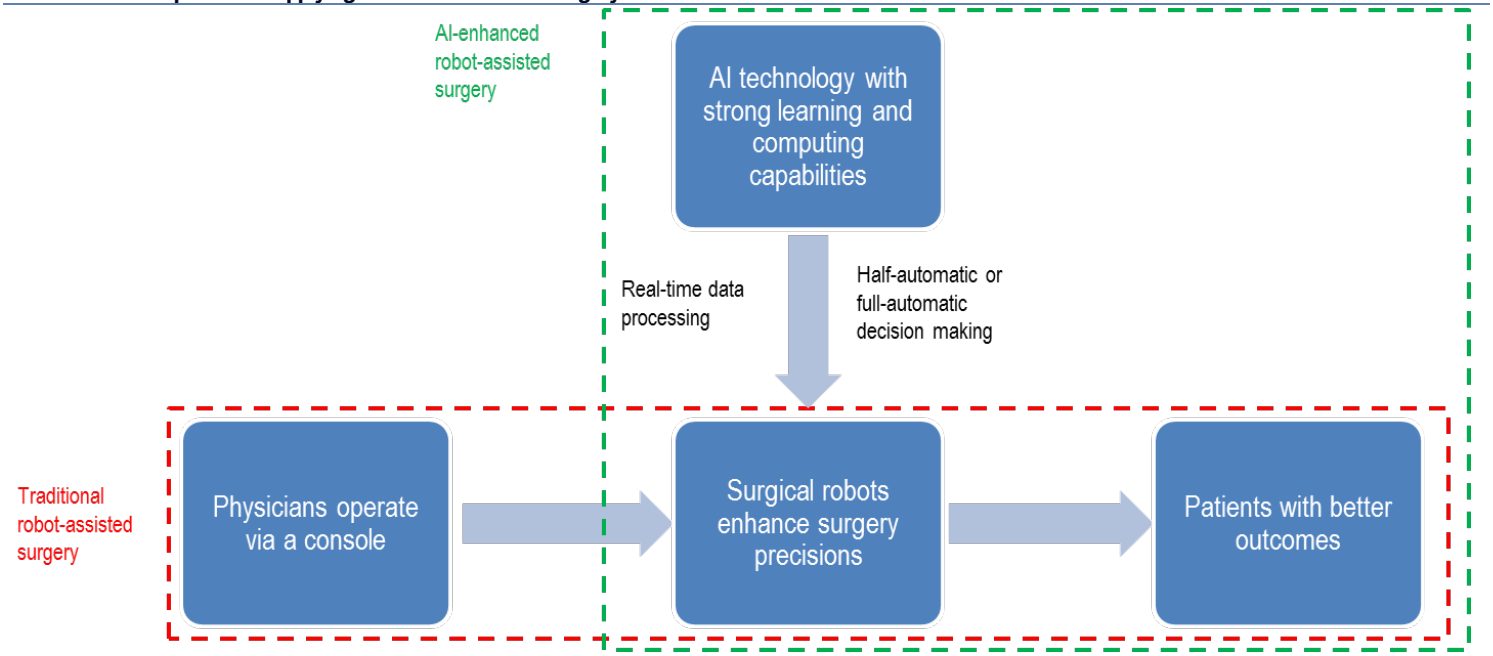
Source: Grand View

The best-known surgical robot is da Vinci, invented by Intuitive Surgical, which was approved in 2000 by FDA and has so far performed 2 million surgeries worldwide. Da Vinci is used to perform precise maneuvers, but the system is not automated at all - humans make every decision and control every move via a console, hence AI used in da Vinci system is still very limited. Even so, the benefits brought by da Vinci include a 21 percent reduction in length of hospital stay, according to an Accenture analysis.

Although still new for healthcare practitioners, robots armed with AI are now able to push the application to a new level, which will further reduce surgeon variations that could affect surgery outcomes in some of the most challenging situations. Advanced analytics and machine learning techniques are being used to help uncover critical insights and best practices from the billions of data elements associated with robotic-

assisted surgery. AI helps surgeons determine what is happening during a complex surgery by providing real-time data points about the movements the surgeon makes during the procedure. Theoretically, AI can even allow surgical robots to function autonomously if sufficient data are given to perform these complex procedures.

Exhibit 8: General process of applying AI in robot-assisted surgery



Source: BofA Merrill Lynch Global Research

Table 3: A sample list of domestic AI start-ups with products/services in AI-powered surgical robot

Company name	Foundation year	Latest round financing (RMB mn)
Hoz Medical	2000	50 (A)
Tinavi	2005	
Remebot	2010	130 (C)

Source: : Company websites, Online news websites such as sohu, BofA Merrill Lynch Global Research

A case study of Smart Tissue Autonomous Robot suggests potential of using robots in soft tissue surgeries

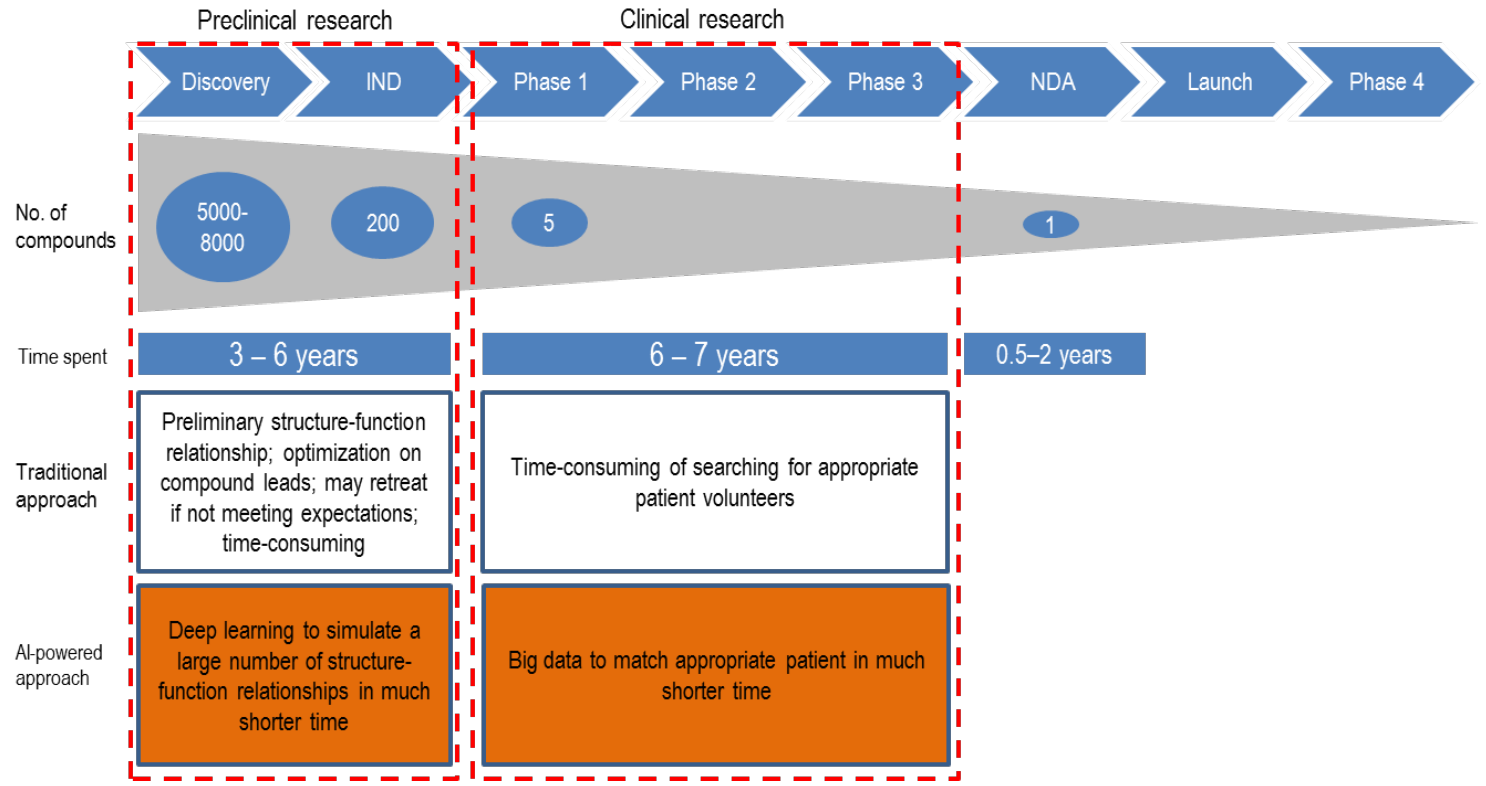
Smart Tissue Autonomous Robot or STAR, developed by Sheikh Zayed Institute for Pediatric Surgical Innovation at Children's National Health System, solves the challenge of using medical robots in soft tissue surgeries. Its vision system relied on near-infrared fluorescent (NIRF) tags placed in the intestinal tissue; a specialized NIRF camera tracked those markers while a 3D camera recorded images of the entire surgical field. Combining all this data allowed STAR to keep its focus on its target. The robot made its own plan for the suturing job, and it adjusted that plan as tissues moved during the operation.

Researchers of STAR tested the automated system in stitching together two served ends of a pig's intestine. To compare the stitching result, experienced human surgeons were given the same tasks. When the resulting sutures were compared, STAR's stitches were more consistent and more resistant to leaks. The robot did get some help. In about 40 percent of its trials, the researchers intervened to offer guidance. In the other 60 percent of trials, STAR did the job completely on its own. The overall results show the big potential of automated surgical robots in the future.

Drug R&D

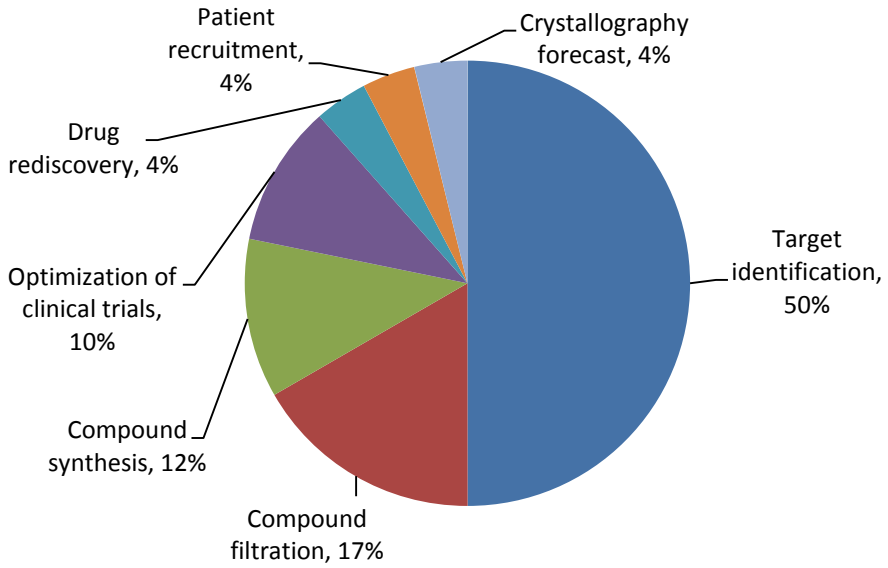
We view this scenario as the most encouraging one in next 5 to 10 years from both a domestic and international perspective. The humongous size of global drug market, the fast-growing R&D expenditure by pharmaceutical companies, the lengthy drug research activities before regulatory approvals, and extremely low success rate from pre-clinical to approval stages, have become strongly internal drivers to force the pharma industry find to a new approach with much higher efficiency and reliability. Here is where we believe AI can show its best.

Exhibit 9: AI technology can be used in the whole cycle of drug R&D process



Source: BofA Merrill Lynch Global Research

Chart 12: Target identification is the most popular direction of AI in drug R&D



Source: VBR

AI can be used almost all stages of drug R&D, from as early as target identification to patient recruitment for clinical trials. A study on recent financing events among AI start-ups in this sub-sector finds that most players focus on preclinical study, specifically, in target identification and compound filtration. By leveraging its strong abilities in natural language processing, imaging identification, machine learning and deep leaning, AI can not only find explicit relationships between compounds and diseases or between genes and diseases with a much faster pace, but also be able to excavate implicit relationships which cannot be easily found by pharmacologists in traditional ways. Here are some AI applications in drug R&D.

Compound synthesis. AI technology can simulate the characteristics of small-molecule compounds and pick out, in just a few weeks, the best candidates for synthesis tests, significantly lowering costs. In contrast, traditional methods need pharmacologists and chemists to do computer-based simulation test for each compound from a candidate pool containing as many as several millions.

Drug rediscovery. Rediscovery is a common approach to find new applicable indications for marketed drugs by cross-matching between those drugs and more than 10,000 targets in human body. AI can establish valuable concepts or hypothesis from millions pieces of info, bringing in exponential improvement in research speed.

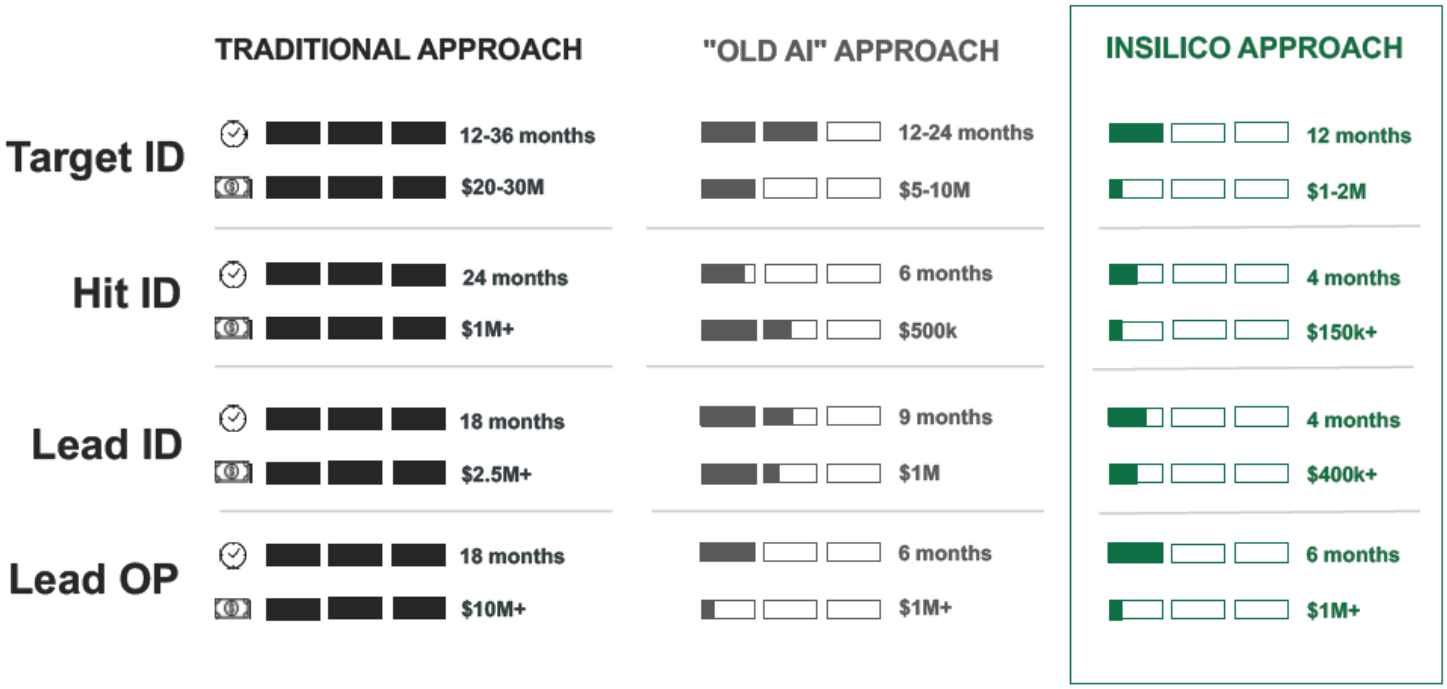
Patient recruitment and optimization of clinical trials. AI also finds itself very useful when a drug candidate is advanced to clinical trial stages. Commonly, finding enough numbers of patients meeting inclusion criteria is both time and finance consuming (in China, patient recruitment is harder than that in developed countries due to the inadequate developments of patient originations). AI is able to compare and analyze a large amount of patient profiles and automatically choose patients meeting requirement with high accuracy in short time. In addition, AI technology can manage and optimize the process in all stages in the lengthy clinical trials, increasing trial efficiency.

Insilico Medicine is working with WuXi Apptec to bring AI based drug discovery to China

Insilico Medicine's AI technology, based on generative adversarial networks (GANs) which can translate visual concepts from characters to pixels, can effectively generate novel molecular structures with desired properties. Chemistry.AI, an AI platform for drug discovery, will arm medicinal chemists with effective tools to look at the various classes of molecules and measure their brain activity and other physiological parameters during the exposure to the molecule. The company also has projects in deep learned multi-disease marker and classifier and predictor of mechanism of action of multiple drugs based on multi-omics data.

The company is currently partnering with Wuxi AppTec through a venture capital investment to boost its AI-driven drug and biomarker discovery platforms.

Exhibit 10: AI technology from Insilico Medicine is able to dramatically reduce time needs for drug discovery



Source: Insilico Medicine

Atomwise successfully identified drug candidates for Ebola virus

Atomwise, a US-based AI start-up, used its AI technology to analyze 7,000 compounds in less than one day and identified two candidates that have potential to control Ebola. According to the company, the time needed with traditional approaches could reach months or even years.

Supported by biological insights about the Ebola virus from researchers from the University of Toronto, AtomNet, an Atomwise technology platform, screens for compounds that bind with high affinity to a defined glycoprotein, which is important for viral entry and fusion. The screening process was completed in less than one day. Top compounds were selected and tested bind affinity to the glycoprotein and ability to prevent Ebola virus entry into cell in an *in vivo* assay. Researchers found that the binding affinity of the best compound was remarkably high and it appeared to act specifically on the glycoprotein.

Table 4: A sample list of domestic AI start-ups with products/services in drug R&D

Company name	Foundation year	Latest round financing (RMB mn)	Latest valuation (RMB mn)
Force Clounds	2012	40	
Taimei Tech	2013	80 USD mn (E)	
XtalPi	2014	42 USD mn (B+)	> 100 USD mn
MedBanks	2014	400 (D)	
LinkDoc	2015	1,000 (D)	> 7,000
Dip-Ai	2017	15 USD mn (B)	

Source: Company websites, Online news websites such as sohu, BofA Merrill Lynch Global Research

Virtual assistant

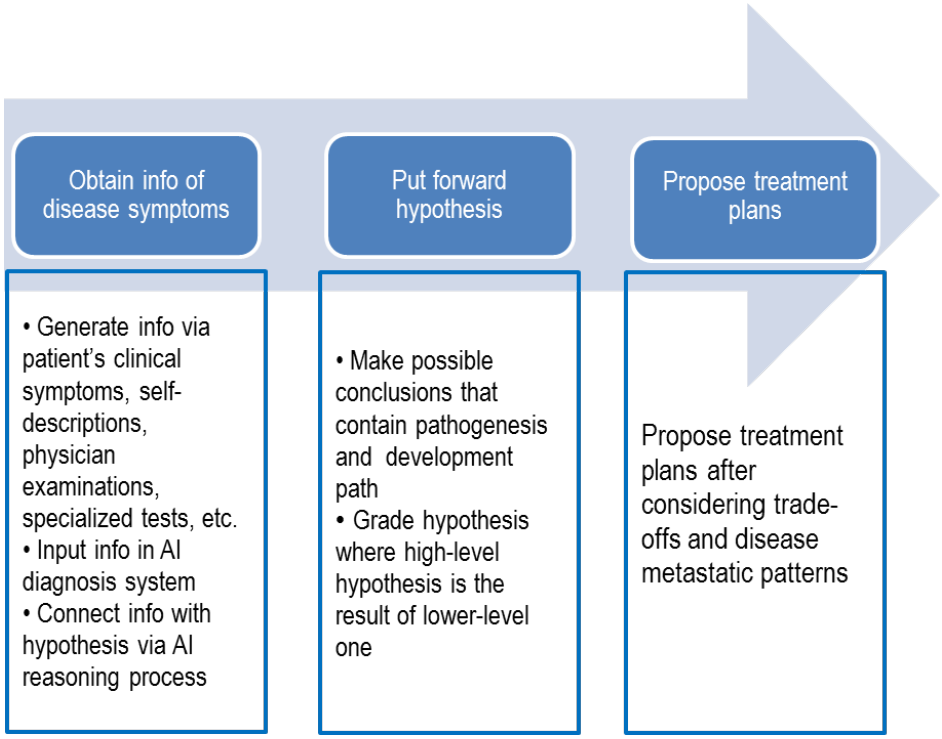
A hospital is a complex organization with multiple departments functioning in a coordinated way. AI technology can thus be used in many spots in a hospital to optimize the overall efficiency, which requires a comprehensive capability of planning, organizing, coordinating and managing staff, finance, equipment and information. As a result, virtual

assistant based on AI technology has been presented in response to the complexity of hospital workflows.

In traditional approach, where people are the major handlers of every process, too much human and medical resource is consumed. Highly trainable with medical knowledge and capable in computing, virtual assistant can perfectly complement human in certain administrative work and provide specialized supports during diagnosis and treatment process. For administrative work such as patient triage, medical records, and pre-inquiry, the technology is smart enough to complete those tasks and can present more time for meaningful communications between doctors and patients.

Further, virtual assistant can be used in diagnosis and treatment processes where possessing medical expertise is an indispensable prerequisite. Virtual assistant can be trained to master expert-level medical knowledge and simulate medical logic of real doctors to interpret symptoms of patient. Ideally, assistant virtual is able to come up with valid diagnosis conclusions and treatment advices. But in real practice the call of treatment solutions must be made by doctors and virtual assistant only functions as a real "assistant".

Exhibit 11: General process of applying AI as diagnosis assistants



Source: BofA Merrill Lynch Global Research

Virtual assistant can also provide hospital managers with decision-making supports via big-data analysis. By collecting data generated by different departments in a hospital, hospital managers can form a deeper understanding on hospital operations and decision-making process can be more efficient.

A case study of using AI in medical records suggests physicians' can spend much less time on records

Dingxiangyuan, an online physician community, estimates that 50% resident physicians in China spend more than 4 hours a day in writing medical records. American Medical Association estimates 15% - 20% career time of a physician is used in paper work such as medical records. Improvements in voice identification have been able to set doctors free from lengthy work of handwriting medical records. Specialized voice identification tool, such as Dragon Naturally Speaking, developed by Nuance, is now widely used in US hospital (covering 500,000 doctors) with an identification success rate of 99%. In China,

such voice identification tools are not widely available. Chinese companies are working to take advantage of the big market potential. iFlyTek has initiated a pilot program of its voice identification tool (with an identification success rate of 97%) in healthcare institutes.

Diagnostic decision support systems (DDSSs) – Ada DX targets difficult rare disease diagnosis

As the correct and timely diagnosis of rare diseases is often a challenge faced by physicians who might lack of knowledge and awareness for approximately 7,000 rare diseases, DDSS is becoming an increasingly helpful tool to assist physicians to diagnose those diseases. DDSSs are expert system that utilizes a diagnostic reasoning process basing on incorporated medical knowledge. Ada DX is a professional DDSS that is currently being developed as a research prototype by Ada Health, an AI-powered healthcare start-up. Different from database-designed DDSS (meaning relying on pre-existing database or publicly available ontology of medical content), Ada DX is built on a specifically-designed knowledge base with the goal of diagnostic accuracy.

Ada DX has shown significant difference (superiority) in diagnosing rare diseases compared with traditional approaches. In a retrospective study including 93 cases, Ada DX suggested the correction diagnosis earlier than the time of clinical diagnosis in 54% of cases. The mean time saved by Ada DX in correct diseases suggestions compared with that by human diagnosis was 3 months. Aside from a timely diagnosis, Ada DX also returned an accuracy of 89% with the system's top disease suggestions.

Table 5: A sample list of domestic AI start-ups with products/services in virtual assistant

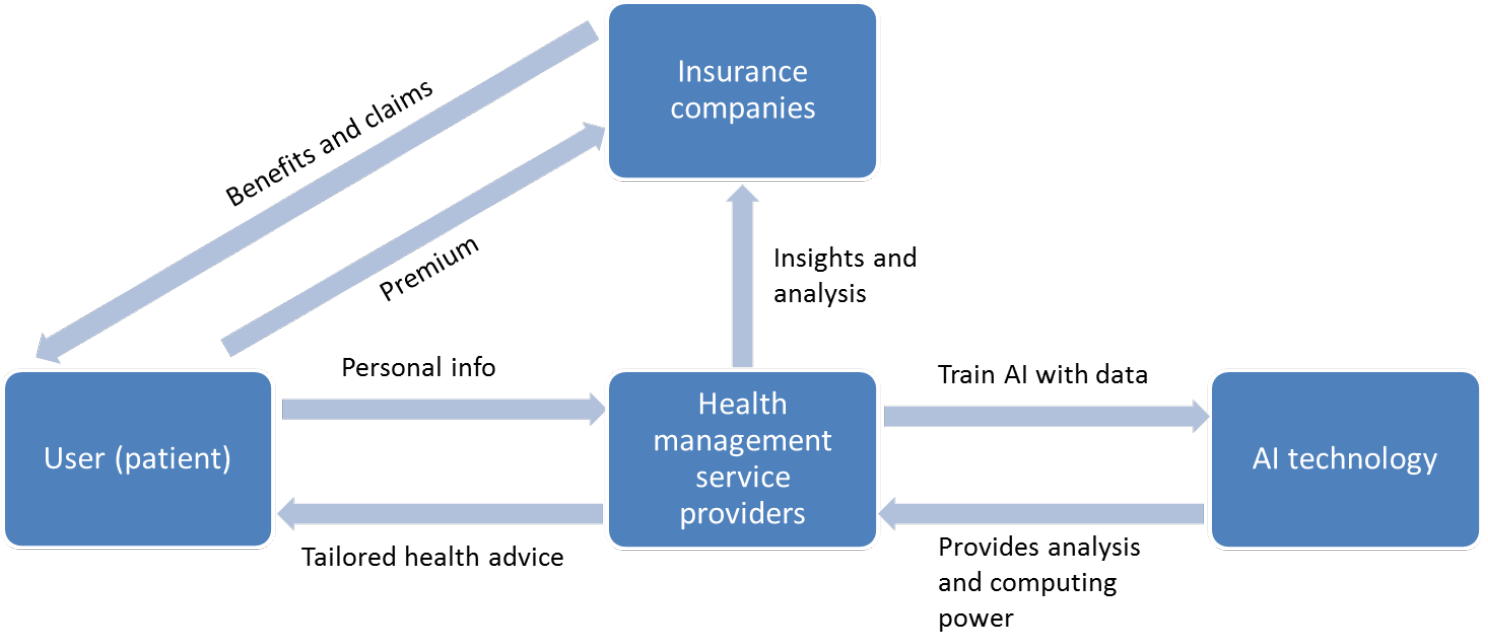
Company name	Foundation year	Latest round financing (RMB mn)	Latest valuation (RMB mn)
Metech	2005	> 1	
Unisound	2012	600 (C+)	> 1,000 USD mn
Witspring	2014		
Ruoshui	2014		
RxThinking	2015		
Broadcare Robot	2015		

Source: Company websites, Online news websites such as sohu ,BofA Merrill Lynch Global Research

Personal health management

This application is another highly competitive sub-sector in China AI healthcare industry. It is generally believed that AI technology can actually help people live a healthier life. The goal can be achieved by the cooperation between patients (users) and AI. Users are required to provide a set of data such as an accurate self-description of disease history, current health conditions and daily activities. By quantify and analyze users' input, AI can effectively keep records of users' daily activities and give health advice to direct users to a healthier lifestyle. Importantly, those advices are specially tailored for individual users and can thus reduce risk. Ideally, no two users should get same advices from AI-powered health management tools.

Exhibit 12: General process of applying AI in health management



Source: BofA Merrill Lynch Global Research

The concept of health management first originated from insurance companies which seek to lower their future payments to policyholders' claims or benefits by helping policyholders stay healthy. In China, there are no applicable data models to evaluate cost/profit profile of health management and insurance companies barely set foot in health management services other than physical examinations. However, to provide better employee well-fare, more and more companies, cooperating with insurance companies, are willing to allocate resources to employee health management, making business-end (both insurance companies and non-insurance companies) the largest revenue sources for AI companies that provides health management services. We give a sample list of domestic AI start-ups with products/services in health management in the table below. We also discuss Jijiankang below given its advantage in collecting historical personal healthcare data as it is part of Ciming Checkup, a large Chinese physical examination company..

Jijiankang has advantage on collecting historical personal healthcare data

Jijiankang is a data-driven, AI-powered health management and medical service company, targeting health management market after physical examination. Currently in China, post-physical-examination services such as patient follow-ups are largely ignored. Jijiankang leverages its capability to integrate examination data and health indicators, forming a comprehensive health record for its users (via smartphone apps and national-wide off-line service centers), which can further be analyzed and assessed using big data and AI technology. As a fully owned asset of Ciming Checkup, one of the largest physical examination companies in China, Jijiankang gains access to 18 million structural data that have been accumulated during the 15-year's operation of Ciming. Jijiankang is able to categorize 1,000 diseases, rate and evaluate health risk factors, and provide user tailored guidance in re-examination.

Table 6: A sample list of domestic AI start-ups with products/services in health management

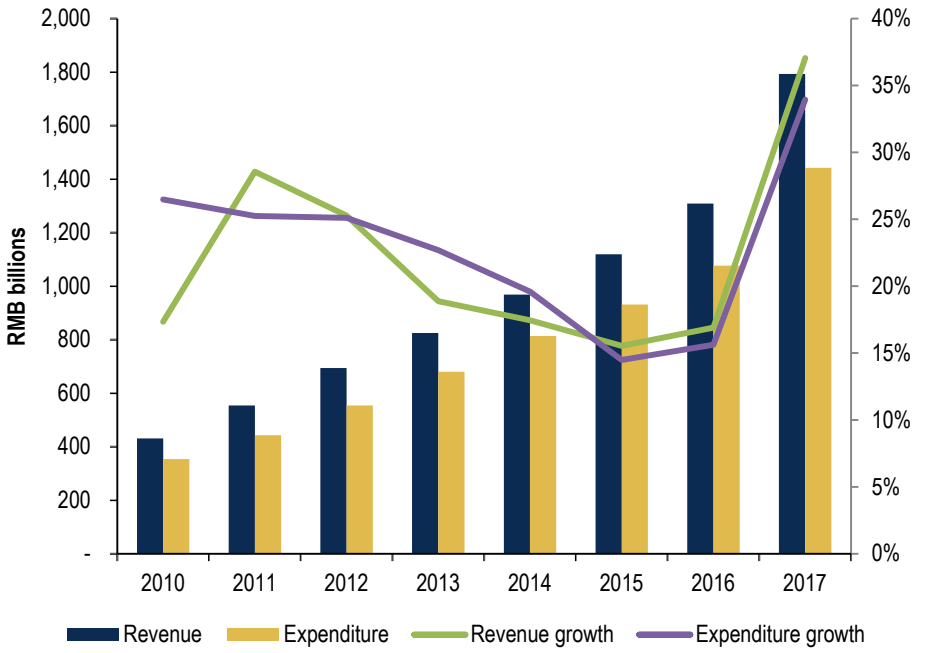
Company name	Foundation year	Latest round financing (RMB mn)	Latest valuation (RMB mn)
MMbang	2003	> 100 (B)	
Dnurse	2013	> 10 (A)	
Jijiankang	2014	60 (Angel)	
Yesudoo	2014		
iCarbonX	2015	1,000 (A)	6,500

Source: Company websites, Online news websites such as sohu, BofA Merrill Lynch Global Research

Expenditure monitoring of Medical Fund

Thanks to the aging population and the expanded population coverage, Urban Basic Medical Security Fund (the Fund) revenue grow rate has been outpaced by expenditure growth in recently years. At the same time, scandals related to fake claims are eating up resources of the Fund. To crack down those scandals with efficiency, regulators are combining AI with other digital tools to monitor the whole process of medical funds, bringing fund monitoring to a brand new intelligent era.

Chart 13: Both revenue and expenditure of Urban Basic Medical Security Fund jumped in 2017



Source: National Bureau of Statistics, BofA Merrill Lynch Global Research

An AI-powered monitor system consists of knowledge base and rule base. The former base includes drug prescription information, diagnosis pathway, clinical guideline, registered prescriptions, etc. The letter base contains all kinds of rules in diagnosis, treatment, documentation, and reimbursement, among others. The system monitors every stakeholders' actions and provide rigorous guideline on what should be done and how. Any violations to the rules will be recorded automatically for corrections and punishments.

In recent years, China government has been encouraging the usage of AI technology in monitoring the operations of the Fund. A pilot program in three hospitals in Yunnan Province from Dec. 2013 to Sep. 2014 lowered the proportion of a certain cost from 24% to 15%. Provinces such as Hebei, Jiangsu and Anhui also saw satisfied results after bringing in the system.

Table 7: A sample list of domestic AI start-ups with products/services in expenditure monitor of Medical Security Fund

Company name	Foundation year	Latest round financing (RMB mn)
Yinghai	2003	
Healthcom	2014	
Shulian Yikang	2015	> 10 (A)

Source: Company websites, Online news websites such as sohu, BofA Merrill Lynch Global Research

Commercial insurance companies

In the context of the dominance of Medical Security Fund, commercial insurance companies in China have not played a big role in health insurance eco-system. For the customers (patients) of healthcare management, AI can follow and analyze customers' activities and reduce benefit/claim payments to policyholders from commercial insurance companies (see exhibit 12). Data have long been a core asset for insurance companies as the basic principal for the industry is the law of large number. However, data have not been leveraged efficiently in industry practice as, traditionally, insurance companies are blunt to customer behavior changes and post-sale services are often absent. In addition, low-efficiency in human operations in many parts of an insurance company's internal process has long been a big obstacle to a better utilization of resources.

Now more insurance companies realize the importance of the application of AI, which can form a highly integrated digitalization system connecting different application scenarios and algorithms. The process is able to excavate and utilize first-hand data directly generated from buy-sell activities between insurance companies and policyholders and cover every spots in the service chain, which could be the groundwork for the improvements in productivity and customer satisfaction.

Alpha Insurance from China Pacific Insurance Company (CIPC)

Alpha Insurance is an AI-powered tool that CIPC developed to help customers choose appropriate insurance products. By simply answering a few questions, Alpha insurance is able to recommend an insurance product that best meets customer's needs. The AI technology behind Alpha Insurance presents customer with consistent service standards with high expertise and objectivity, which varies a lot among human sale representatives. According to 2018 annual report of CIPC, the total visits to Alpha Insurance reached 6.5 million and CIPC will integrate more functions into the tool in the future.

What can we learn from IBM's Watson?

Story of Watson

Using advances in natural language processing and analytics, IBM lab developed Watson technology, named after IBM founder Thomas J. Watson, which can process information similar to the way how people think. Such technology represents a significant shift in the ability for organizations to quickly analyze, understand and respond to vast amounts of Big Data. The ability to use Watson to answer complex questions with speed, accuracy and confidence has enormous potential to improve decision making across a variety of industries from health care, to retail, telecommunications and financial services.

IBM has invested significantly into Watson's innovativeness. In January 2014 the company announced that it would invest an additional $1 billion in the technology, and, to apply Watson in healthcare, it created a new division to grow the business. IBM has done several acquisitions to enrich its patient information database and enhance its analytics capability in healthcare from 2014 to 2015.

Optimism toward AI technology once drove capital markets to hold a positive view on IBM's Watson system. French bank Credit Agricole predicted that 12% of IBM revenue in 2018 could be generated from Watson-related products/services. However, the reality seems to hit it hard on that optimism – according to IBM 2018 annual report, solution software, the segment including Watson, accounted for 16% of 2018 total revenue. The company doesn't give specific number for Watson, though. Given that Watson is not a substantial contributor in this segment, its share in the segment should not have reached a significant level. Watson division experienced major layoffs in 2018, which may indicate its inferior performances in commercialization progress. At the same time, Watson is facing talents loss to other technology giants such as Apple and Google.

As one of the first companies to make a major push in AI commercialization, IBM may have been suffering from its ambition: it took an aggressive, marketing-first approach to Watson, promising attractive achievements that didn't accurately portray what the system could actually achieve. To attract more customers, Watson was promised by IBM marketing staff to complete medical tasks that currently beyond its abilities.

We use several failed cases of Watson to illustrate our points here.

Failed Watson applications

Disease diagnosis at MD Anderson Cancer Center
MD Anderson Cancer Center at University of Texas dropped its collaboration with IBM Watson, only three years after its ambiguous plan working with IBM was announced. Before the termination of collaboration, the AI system seems to gain increasing acceptances in the center as it could give out medical recommendations which were agreed by medical experts 90% of the time. The termination decision was based on the incompatibility of Watson with Anderson's new electronic medical records system and the unaffordable cost to use the system, according to a University of Texas audit report. However, a probably more important reason could be a suspicion that early test results might have been generalized too fast given early tests only treated limited forms of cancer that may have been easier to diagnose and treat. For instance, the early version of the AI system targeted patients with a lower-risk form of leukemia, called myelodysplastic syndrome (MDS).

Drug R&D at pharma companies
AI is supposed to find growth in drug R&D activities which need to process of millions or billions data points. However, skepticism starts to replace excitement around Watson on that front. In early 2019, IBM stopped selling Watson to pharmaceutical companies Subsequently an IBM spokesperson said that the company was not discontinuing Watson for drug discovery but instead was refocusing on the field of clinical development where the company see greater market need. The Watson application in drug R&D seemingly has fallen behind expectations

Potential lessons to be learned from Watson

Clearly specify what AI can and can't do in healthcare. Both AI and healthcare are complicated science and the integration of two fields is bounded to be a hard, long way. Technical department should have a close communication with marketing department, in order to present customer a true picture of what the AI products can do.

Trade-offs between profitability and acceptance. Developing AI in healthcare technology usually consumes a large amount of financial and human resources before the products can be commercialized. However, AI companies may need to employ a customer-friendly pricing strategy, which sacrifices profitability for acceptance first. High cost may drive away potential customers as well as reduce the overall benefits that can be brought to users in initial applications of AI technology.

Applying AI in healthcare is going to be a gradual process, which might not have a shortcut. Although many media and healthcare practitioners take a positive view on Watson's application in healthcare, the lack of high-quality data (such as data collected from randomized trials) and the extremely high complexity pertaining to many healthcare sub-sectors have deemed more AI healthcare research is needed. Natural language processing technology has been developed and refined in last five year and the technology is much better than it used to be, yet it is still significantly worse than humans in understanding medical text. This may partially explain why AI's potentials have only been demonstrated in carefully controlling experiments and variations in reality could make the system unreliable in dealing with real-world problems.

Future directions for AI in China healthcare

Although AI technology in healthcare is still facing issues, its potential in revolutionizing the landscape of China healthcare is clear, we think. An improved healthcare system with more efficiency and less cost could be gradually implemented in the next a few decades with the assists of AI. The China government is trying to create a favorable environment for all parties that participate in AI healthcare. China's VC funds and healthcare companies are also supportive, providing funding for AI based healthcare start-ups with advanced technologies and high ambitions. We believe AI technology and systems will grow to become an indispensable part of China healthcare. Below, we highlight the potential future direction we think AI in China healthcare could take.

Target data incompleteness and inconsistence

AI in healthcare companies depend on data to develop applications, thus making data quality and data size the central area to compete. China's large population means large amount of medical data has been and is being generated in daily life. However, factors including relatively few connections among hospitals and departments, non-unified disease history report and other data issues have made as much as 75% of medical data as non-standardized/non-structured, which are hard to be used in AI applications.

Avoid over-concentration in just a few sub-sectors

Because of the high volume of imaging data and relatively high data standardization, most AI in healthcare start-ups specialize in medical imaging. Personal health management and hospital management also gain some attentions given their relatively low entrance barrier. Other sub-sectors such as drug R&D and precision surgery only see a limited number of Chinese start-ups due to the high expertise needed in those fields. Over-concentration in one or two sub-sectors of AI in healthcare could limit the overall growth of AI healthcare eco-system.

Develop AI applications in both diagnosis and treatment

Many AI technologies have been successfully applied in disease diagnosis, acting as a powerful assistant to doctors. However, it will still be difficult for AI to fully replace doctors because much characteristics in disease diagnosis that can hardly be parameterized. In contract, parameters are presented in many aspects of disease treatment and standard-of-care exists in many disease treatment regimens. AI can accordingly utilize those standardized parameters to generate personalized treatment plans for patients, which might provide better treatment results. However, only a small number of AI in healthcare companies is focusing on AI based disease treatment. We think a product mix containing AI solutions in both disease diagnosis and treatment could gain more adoption. Additionally, synergies could be expected by combining the full service AI tool with doctors' daily work involving both diagnosis and treatment.

Identify more business models

No or low profitability is a common feature for all start-ups in AI in the healthcare industry globally, especially in China where the industry is still in its infancy. Healthcare industry typically applies vigorous standards in everything it does since it is dealing with human lives/health. This feature might make healthcare industry look picky in terms of considering whether to adopt novel tools. AI start-ups' weak market position in the eco-system also could make this a buyer's market, in our view. Hence, it is essential to identify new business models for AI in healthcare.

Make industry standards for AI products

Policy plays a critical role in the commercialization of AI products in healthcare. Due to the short history of AI in healthcare products, Chinese regulators have not released guidelines or policies specifically for those AI based healthcare products. Industry standards and a corresponding standardized test frame need to be established before any AI based healthcare products can legally be considered as safe and reliable. The

process of establishing those standards could take years and should be started as soon as possible.

Supply more expertise with both AI and medicine backgrounds

Medicine and AI are among the most advanced subjects and it takes years to train students to become qualified in either areas. Those with expertise in either subject are in short supply, and there extreme shortage in expertise with both backgrounds. According to LinkedIn research, China has only 50,000 talents in AI industry compared with 850,000 in US. The number of doctor per 10,000 people in China was 24 in 2017, significantly lower than that in developed countries.

Conduct more fundamental R&D for AI in healthcare

In terms of AI related research publications, China is catching up with other developed countries. However, many AI research activities are for AI applications. China is still behind in fundamental research for AI in healthcare, such as AI algorithms, AI mathematical models, hardware for accelerating AI computation, and large data depository for AI usable datasets.

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