The commercial value and viability of a non-invasive knee cartilage injury detection device

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ABSTRACT
Knee osteoarthritis (OA) is becoming more common, and is affecting more young population than before. Symptoms including pain and stiffness become present only when the injury is irreparable, and the most effective treatment is surgery. The ability to detect the injury early can prevent the disease progression to that stage with appropriate interventions, saving patients from physical suffering as well as financial cost. This paper assesses the commercial value of such a device that can detect early stages of knee OA injury. The information is useful for private investors as well as policy makers in setting funding priorities. We used questionnaires to collect willingness-to-pay data from 400 respondents in Khon Kaen municipality, and used this data to make revenue projections for a provider of knee injury reading service. We found that the revenue is substantial even for smaller operations like clinics. The willingness-to-pay for a device is about 190,000 THB per year for a small clinic requiring 60% operating profit margin, and goes up to 7.89 million THB per year for a large hospital requiring 30% profit margin. We conclude that if device developers can keep their costs below this willingness-to-pay, an early detection device for knee injury is commercially viable and can reach a wide population.

Introduction

The ability to walk is arguably the most symbolic aspect of a person's independence, and it significantly lightens the burden on caretakers, e.g. for the elderly, for those living dependently. Knee osteoarthritis causes pain, aching, and stiffness, all of which affect their ability to walk[1]. Those with knee OA are limited in their daily functions[2], becoming heavier burdens on care-takers if dependent. The most effective treatment for knee OA is surgery, which is expensive and out of reach for lower income patients. The prevention of disease progression to surgery stage would improve the well-being and reduce the financial burden of a large part of the population.

Symptomatic knee OA is characterized by progressive articular cartilage deterioration and resulting in pain, aching or stiffness in the knee[1] affecting quality of life and psychological well-being[3]. Risk factors of OA include old age, female gender, obesity, previous knee injury, repetitive use of the knee joint, high bone density, muscle weakness and joint laxity[8]. Knee cartilage injury can also be found in asymptomatic young individuals. A recent study has reviewed the knee MRI of 230 asymptomatic individuals and found 62% with knee cartilage injury, where approximately 20% were 40 years old or younger[9]. In another study done in a larger population pool, 24% of asymptomatic individuals developed knee cartilage injury[10]. This asymptomatic group is likely to later develop symptomatic knee OA.

When diagnosed with knee OA, physicians typically prescribe conservative therapy, which includes both pharmacological and non-pharmacological methods. Non-pharmacological therapy includes, but is not limited to, weight loss for the overweight or obese, exercise, physical therapy, cane use, and knee bracing[2,11]. Pharmacological approach includes the prescription of oral or topical nonsteroidal anti-inflammatory drugs (NSAIDs) for pain relief, and intra-articular glucocorticoid injection[12]. However, NSAIDs are associated with upper gastrointestinal irritation for non-selective NSAIDs and risk of cardiovascular disease for selective NSAIDs[13].

Osteoarthritis (OA) was estimated to affect approximately 14 million people in the United States, where the disease affects not only the elderly but also younger and middle-aged adults[1]. Knee OA is becoming more common among the younger population[3]. In Thailand, according to data provided by the Thai National Health Statistics Office, the number of knee replacement surgeries performed in 2016 (B.E.2559) among those under the Universal Coverage (UC) health insurance scheme amounts to more than 11,000[7]. The total number of surgeries is likely substantially higher as these count only those who cannot afford the surgery on their own. The ability to detect the injury early can help patients avoid surgeries and allow physicians to develop treatments for various stages of the disorder.

OA might be preventable as there are several risk factors other than old age[14]. Weaker quadriceps in radiographic OA[15] suggests muscle strength training could further protect the knee beyond weight loss. Knee joint screening is currently not on the list for annual physical checkup. At present, MRI is arguably the most powerful tool in detecting many pathologies including knee cartilage injuries[4]. However, the machine is expensive and out of reach for most health care service providers[5]. The current rate for an MRI of the knee is about 7,200 THB, which is more than half the current average salary of Thai wage workers of about 14,000 THB in 2016[6]. An effective and less costly screening device to assist in knee OA prevention seems likely generate health benefits reaching a broader population.

The case of the MRI illustrates that the ability of any health technology to improve lives depends on the ability of the private sector to build a business around it, offering a price that is within reach. That ability depends, first and foremost, on the revenue potential of the technology. Hence, this paper provides estimates of revenue potential of a knee cartilage injury detection device (KIDD) in Thailand, as a less expensive and more accessible tool for early detection of knee injuries. We use the contingent valuation method (CVM) to elicit willingness-to-pay for knee injury reading service, and assess the

commercial viability of offering the service and of making such device available. As of the writing of the paper, there is no standard practice to treat early stages of knee cartilage injury, as most are undetected.

Materials and methods

The assessment of demand for, and commercial viability of, the knee injury reading service depends on estimating the value of a non-traded item, since it is not available in the market. This study applied the contingent valuation method (CVM) to assess the value of the device to potential customers. The method involved asking the target group the question "how much would you pay for this service?" or "will you accept the service at this price?" and then offer a list of prices[16]. We used results from CVM to project the revenue for providers of knee injury reading service, and deduce the commercial viability based on these projections.

Demand assessment using Contingent Valuation Method (CVM)

We used the Contingent Valuation Method (CVM) to estimate the willingness-to-pay for a knee injury reading service. This method is regularly applied in the medical context to find the value of a service not traded in the market. See van den Berg, Brouwer, & Koopmanschap (2004) for an overview of this and other methods[16].

After identifying the target market, we asked people whether they were willing to accept the service at various prices. This was to replicate purchase decisions in real life where consumers look at the posted prices to determine whether to buy the product. The data gathered from the surveys were then aggregated to estimate the demand curve relating price to quantity purchased.

Since survey participants were not familiar with knee injury and early detection, data collectors provided the following information before conducting the survey.

1) The importance of healthy knees in living a full life

2) Current knee injury detection practice

3) Knee injury detection using non-invasive device

The above information was also available on the questionnaire for respondents to read and reconsider throughout the interview process. Respondents could also have the interviewers read the information to them. In this study, none of the participants needed assistance.

The CVM questionnaire was the main tool of analysis, and biases could occur if it is not carefully designed. We considered and addressed 3 main sources of error where our instruments might be biased, following the literature[17]. These were 1) understanding the knee reading service and its importance, 2) correctly stating their willingness to pay, and 3) the representativeness of the data. We consulted with a fellow researcher with experience in CVM to help with the information presentation, and pre-tested the material by having colleagues and research assistants read the information and provide feedback. In regards to the second source of bias, we designed the question as yes/no (binary) at given prices, which should mimic real world purchase situations better than asking them to state a price. For representativeness of the data, we randomly selected participants who fell within the target age range. This latter point was discussed in more detail below.

Survey sample

The sample consisted of people aged 18 - 40 from Khon Kaen Municipality (Amphoe Mueang) in Thailand's Northeast region. The selected age group was in accordance with knee treatment experts who indicated that they would likely target the population between the ages of 18 - 30 for early knee injury detection and prevention. The research team would visually guess the age of each passerby, and verbally recruited one out of about 2-3 of those who seemed to meet the age criterion. Recruitment of respondents took place at crowded locations where the target group were most likely to be found. These included locations at a university campus and a public park near the city center. Since the average income in the Northeast is lower than that in Bangkok or the

central region, the estimated willingness to pay can be lower. We were able to collect data from 400 respondents. Females made up about 53% of the sample. Summary statistics of the respondents are given in the table below.

Table 1 Summary statistics of survey respondents

Variable	Observations	Values (SD)
Age (years)	400	24.01 (6.01)
Monthly income (Thai Baht)	282	9,598.40 (7978.40)
Female (%)	400	52.5%
College Graduate (%)	400	38.5%
Occupation		
Student (%)	400	65.5%
Government worker (%)	400	18.5%
Private sector worker (%)	400	5.3%
Agriculture worker (%)	400	3.5%
Self-employed (%)	400	2.3%

Note: Source from authors' calculations

The respondents did not show obvious physical disabilities. The income level of the sample was about 4 times the regional poverty line of 2,417 THB in 2018[18]. The sample was not screened for any medical condition, nor were they asked about existing health issues. The majority of respondents were college students, since the city was home to a major regional university and a few other technical colleges. A different sample consisting of more working adults than students would likely give different results, even if they came from the same age group.

The survey asked respondents to answer either "yes" or "no" to accepting knee injury reading once during the coming year at various prices. The prices ranged from 50 to 2,000 baht for checking both knees. We solicited willingness-to-pay information for two scenarios. In scenario 1, the service requires required a one-week advanced appointment. Scenario 2 was the same except there was no advanced appointment necessary. With binary responses, the sample size was calculated as[19].

$$n \geq \frac{t^2 pq}{d^2}$$

The sample size, n, was determined by the acceptable t-statistics, t, based on the acceptable risk of a type-I error (or statistical significance), α, the proportion choosing each of the binary options, p and q, and an acceptable margin of error for the proportion, d. In this study we chose an acceptable margin of error of 5%, an α level of 0.05, and assumed $p = q = 0.5$. This resulted in a sample size of $n \geq \frac{1.96^2(0.5)(0.5)}{0.05^2}$ = 384 respondents.

Results

From the questionnaire responses, we have data on people's decision to accept or reject a knee injury reading at various prices. This information is used to calculate the average willingness-to-pay for a knee injury reading, the optimal service price, revenue projections, and commercial viability. It is important to note that the sample used in this study is not representative of the market for any particular potential service provider such as a clinic or hospital. The selected

age range is likely younger than patients that most clinics or hospitals receive, and their willingness to spend on health services is likely lower. Their student status likely makes their willingness-to-pay even lower than in the working population. Thus, we view these results as conservative (lower bound) estimates of willingness-to-pay, optimal price, and revenue projections.

Willingness-to-pay

The overall average willingness-to-pay for a knee injury reading service with 1-week advance appointment is 761.31 THB (SD = 561.85, n = 389), and is 1,019.52 THB (SD = 625.80, n = 392) without an advance appointment. These are computed as the average of the maximum price where respondents still accept the service. We lose about 10 observations for these calculations, because some respondents report not willing to get a reading even if it is free, implying that they are not in the relevant market and are thus not considered in the willingness-to-pay estimation. We can see that the appointment period has some effect in reducing people's willingness to pay for

the service. This illustrates that people consider not only financial but convenience and time costs in obtaining the service.

Service price and revenue

It is instructive to show the additional revenue per patient per year from offering knee injury reading service. This is computed as

$$revenue\ per\ patient = \%\ taker \times price$$

The first term, % taker, is the percentage of all patients who accept the knee injury detection service at the offered price. The additional revenue is on a patient-year basis. They will apply only ONCE to patients that visit the service provider, regardless of how many times they visit after that. Thus, these are revenues per first-visit patient at the service provider, referred to as "new patients" for conciseness. The total revenue generated is this number multiplied by the total number of new patients. The table below summarizes the additional revenue per patient generated from offering the service at each price.

Table 2 Additional revenue per patient for knee injury reading provider

Price offered	1-week appointment		No appointment	
	% taker	Revenue per new patient (baht)	% taker	Revenue per new patient (baht)
0	97.0%	0.00	97.3%	0.00
50	96.0%	48.00	97.3%	48.63
100	90.8%	90.75	96.3%	96.25
200	79.5%	159.00	89.3%	178.50
400	61.3%	245.00	75.5%	302.00
600	40.5%	243.00	60.3%	361.50
800	30.0%	240.00	47.0%	376.00
1000	22.0%	220.00	35.0%	350.00
1500	7.3%	108.75	20.3%	303.75
2000	4.5%	90.00	14.3%	285.00

Note: Source from author's calculations

The maximum additional revenue per new patient under each scenario is highlighted, as well as the corresponding prices. In the case of a required 1-week appointment, the price that maximizes additional revenue per first-visit patient is 400 baht per reading, taken up by 61.3% of patients, and the provider generates 245 baht per patient in additional revenue. Under no-appointment, the price is 800 baht, taken by 47% of patients, generating 376 THB additional revenue per patient visiting the provider for the first time in the course of a year.

The actual revenue a service provider will generate depends on the age and income characteristics of their typical mix of patients, since age is found to have a negative effect while income has a positive effect. Multiple Regression estimates (not reported here) show that an additional year in age is associated with about 20-30 THB lower willingness-to-pay, while an additional 1,000 baht in monthly income is associated with about 26-27 THB higher willingness to pay.

Revenue projections

Total revenue will depend on the total number of service recipients. As with most new technology, there will likely be an S-curve life cycle for the number of users[20]. This would then translate to a revenue trajectory that rises and then falls over time. In this work we assume a constant revenue stream that ends abruptly at the end of the cycle, which is assumed to be several years. We make projections on a yearly basis to avoid making careless assumptions on the length of this cycle. The constant-revenue assumption understates the importance of increased popularity towards the middle of the cycle, and overstates the use rate at the beginning and at the end. Without knowledge of their relative strength, we assume that these balance out and therefore use the constant revenue model and compute revenue streams per year.

According to a practicing physician we spoke to, about 20 - 30 new patients per day is plausible for clinics. This translates to about (20,30)/day x 365 days = 7,300 – 10,950 non-repeat patients per year. For hospitals, the estimated number of visit is 50 to 70 patients per day. The annual non-repeat visits for hospitals will thus be about 18,250 to 25,550 non-repeat patient visits per year.

The resulting projections of additional revenues generated are shown in table 4 for various new visit scenarios, using the no-appointment optimal price (800 baht) that generates 376 baht/new-visit in additional revenue.

Table 3 Annual revenue scenarios for various numbers of new visits per day

New visits per day	Total annual revenue (baht)
5	686,200
10	1,372,400
25	3,431,000
50	6,862,000
100	13,724,000

Note: Source from author's calculations from questionnaire responses

Commercial viability for a producer of knee injury detection device

The above results show that a clinic serving 25 non-repeat patients per day can expect to earn about 3.4 million baht in additional revenue per year by offering knee injury reading service.

More traffic would generate more revenue. Private hospitals receiving about 50 new visits per day can generate 6.8 million THB per year. To determine the viability of a business that produces and sells and/or licenses the use of a knee injury detection device, it is important to know the potential

revenue they can generate. The willingness-to-pay of service providers for the device can give this information.

The revenue that service providers generate represents theoretical upper bounds of the willingness to pay per year for the device. The true willingness to pay will also account for cost and required profit margin. The cost of service will vary across establishments, and is likely lower per unit for larger operations due to economies of scale. A larger cost and required profit margin will reduce the willingness-to-pay for the device.

We assume a constant cost per reading of 100 baht, which includes overlays as well as other variable costs. Under the no-appointment scenario, where the optimal price to charge is 800 baht the willingness of clinics and hospitals to spend per knee injury reading is

$$800(1\text{-profit margin})\text{-}100$$

With these assumptions, we can then compute the hypothetical willingness to pay of clinics and hospitals for obtaining a knee injury detection device for 1 year, per non-repeat patient. Under the no-appointment scenario, 47% of all patients (0.47) accept the reading at the price of 800 baht. Thus the willingness of clinics and hospitals to pay, per non-repeat patient is

$$(800(1\text{-profit margin})\text{-}100)\times0.47$$

The highest profit margin that still allows positive willingness to pay from providers is 87.5%. For illustration, the table below shows the willingness-to-pay per patient at profit margins of 30% and 60% of the price, under the no-appointment case (800 baht per reading, or 376 baht per non-repeat patient) for various targets of profit margin.

Table 4 Willingness of clinics and hospitals to pay for KIDD per new visit

Profit margin (% of revenue per new visit)	Profit per new visit (baht)	Willingness to pay per new visit (baht)
30	112.8	216.2
60	225.6	103.4
87.5	329	0

With the information from the table, we can compute total willingness to pay in hypothetical cases for service providers. For illustration, the table below provides results under 30% and 60% profit margins.

Table 5 Willingness to pay for knee injury detection device for one year (million baht)

Profit margin	New visits per day				
	5	10	25	50	100
30	0.39	0.79	1.97	3.95	7.89
60	0.19	0.38	0.94	1.89	3.77

The willingness to pay for the device ranges from 0.19 million baht per year in a clinic that expects 5 new visits per day and a 60% profit margin on additional revenue per patient, all the way to 7.9 million baht per year for a provider expecting 100 new visits per day and a 30% profit margin. There certainly seems to be room for buyers and sellers to meet to agree to a price that benefits both parties. Manufacturers and/or contractors can aim at keeping their costs of manufacturing and maintenance of the device within this range.

Discussion

The above results can inform business decisions as they provide estimates of potential revenues to be generated. Manufacturers and/or contractors can aim to produce the device or provide the service at the cost under the willingness-to-pay. They should also consider alternatives available to clinics and hospitals for knee injury testing, which will tend to lower the price consumers are willing to pay and thus the price they can charge and the ensuing revenue. A manufacturer of the device might also consider research institutions and sports teams as potential customers, in addition to clinics and hospitals as outlets for their product. These establishments will likely have their own willingness-to-pay based on different sets of factors, and more accurate estimates of potential revenue will require further investigation.

The estimates also show the significant value that people place on early detection of knee injury. Health policymakers might use this as indication of the social value that can be generated if a device or technology is available to serve this purpose, and set funding priorities accordingly. In addition, if such a cheap, non-invasive device becomes available, it might help some patients to avoid surgery as they consult with their physicians on how to approach the injury. At the same time, the measurement allows a collection of data on knee OA and its progression, across various segments of the population, which is essential for research to advance the science of treatment and prevention.

An important shortcoming in these estimates of the willingness to pay is in the use of questionnaires, where respondents may behave differently in real life. This is a major limitation of the so-called "stated-preference" method that tend to overstate willingness-to-pay compared to the "revealed-preference" method where actual behavior is observed[21,22]. Furthermore, respondents are framed to consider only the one decision at hand, which is whether to accept the service at particular prices. Different types of framing or presenting the service can affect real usage[23]. However, revealed-preference and alternative framing can be costly to carry out, and are appropriate when more funding is available and the stakes are higher[17].

Finally, the commercial viability assessed here assumes that the system can generate a business to capture the willingness-to-pay of both customers and service providers. This is a very strong assumption, as businesses, especially startups with their high-risk and high-reward nature, routinely fail[24]. Issues like promotions, customer relations, product design, production, supply chain, and even labor relations all contribute to a successful business. Without these in place, the values that customers are willing to pay cannot be translated to business income as businesses fail to capture them.

Conclusion

Early detection of knee cartilage injury is of medical value as it allows for early treatment of the condition as well as evidence-based study of its progression. If available, a wide of the device can improve the health outcomes of those at risk of knee OA, which is a growing population. The results in this study show substantial potential for commercial value as well, where the plausible range of service price seems sufficient to generate profit for potential manufacturers as well as service providers.

Take home messages

Offering knee cartilage injury reading can generate substantial revenue from the target population, both in small scale and in large scale. This translates to a sufficiently high willingness-to-pay of service providers for a knee injury reading device. Research and development of the device is likely to generate a satisfactory return. The service can reach a wider segment of the population than the current technology if priced appropriately, which will contribute to improvement in treatment practices and health outcomes of knee OA patients.

Conflicts of interest

Acknowledgements

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