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Review

Trends in the cost-effectiveness level of percutaneous coronary intervention: Macro socioeconomic analysis and health technology assessment

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SUMMARY

Percutaneous coronary intervention (PCI), one of the most prevalent techniques of revascularization, is a procedure that remarkably improves treatment outcomes. However, it consumes large amounts of medical resources and has resulted in an increased socioeconomic burden due to the increasing number of target patients. In recent years, there have been sporadic discussions, both in Japan and other countries, regarding the optimization of interventions and the perspective of medical economics. Based on this, previous studies on PCI-related cost-effectiveness were reviewed in order to consider the current level of medical economics regarding PCI. Using the databases MEDLINE and EMBASE, a survey involving data from original articles and systematic reviews was conducted from January 2010 to August 2022. Conditions were not imposed on the evidence level due to the paucity of studies, although field studies were prioritized over simulation studies. The macro medical economics of acute myocardial infarction treatment, which is the primary target of PCI, were generally at an average level when compared to those in other countries; however, there is room for further improvement in Japan's performance. Revascularization in a population with multivessel coronary artery disease showed that coronary artery bypass graft surgery tended to be more cost-effective than PCI in the long-term setting. However, it was suggested that PCI may be more cost-effective in patients with SYNTAX Score ≤22 or left main artery disease. A cost-effectiveness report for stable angina patients was not in favor of PCI over medical therapy. Moreover, there were some reports showing the medical economic superiority of early myocardial ischemia evaluation, and it was foreseen that active selection of patients will contribute to the improvement of the overall cost-effectiveness of PCI. In order to further improve the socioeconomic significance of PCI in the future, it is necessary to aim for harmony between clinical practice and health economics.

Introduction

Revascularization restores blood supply to the ischemic myocardium to reduce ongoing injury and ventricular irritability, as well as improve short- and long-term outcomes, particularly in patients with acute coronary syndrome (ACS). One of the main methods of revascularization is percutaneous coronary intervention (PCI). Against the background of remarkable improvement in treatment outcomes, PCI has been widely used in Japan, and it is considered that quantitative sufficiency has been secured. On the other hand, PCI is a procedure that consumes a large amount of medical resources, and has resulted in an increased socioeconomic burden due to the increasing number of target patients. Amid such a trend, in recent years, there have been sporadic discussions, both in Japan and other countries, regarding the optimization of interventions and the perspective of medical economics. Based on the above, this paper summarizes the current cost-effectiveness level of PCI and helps develop this area. Concretely, we first discussed macro medical economics in the area of ischemic heart disease. Further, based on this, we compared the cost-effectiveness of PCI with coronary artery bypass graft surgery (CABG) and medical therapy. The medical economics of myocardial ischemia assessment and intravascular ultrasound guidance during PCI was also reviewed. Based on these findings, considerations to improve the medical economics of PCI were added.

Background: international medical economics of ischemic heart disease treatment

The medical systems of many countries have historically operated as part of the social security system, owing to the high public interest from

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the necessity for all people. Further, against the backdrop of securing a stable supply, the pricing of medical services has often been based on costs. Numerous developed countries face structural issues, such as declining birth rates, aging populations, and rising costs of medical services. Thus, verification of the clinical efficacy, economic burden, and public price levels has become a matter of urgency [1]. Therefore, with the aim of ensuring a smooth succession of the healthcare system to the next generation of stakeholders, there is a growing momentum for social consensus building on appropriate economic burdens commensurate with the value of healthcare services. As part of this, there is growing interest in the verification of price levels that takes performance (cost-effectiveness) into consideration [2]. The cost-effectiveness evaluation system was introduced into the drug pricing system mainly in Europe in the 2000s and has since spread worldwide. Against this background, discussions on value assessment and price levels in the medical field are being conducted with various approaches, taking cost effectiveness into consideration.

In particular, these themes are becoming more important in the quasi-public medical market, such as the universal health insurance system of Japan, where medical resources consist of social premiums, general taxes (including subsidies), and patient out-of-pocket expenses. For example, rising drug prices and procedure fees have a structure that rebounds on social and individual burdens. Therefore, the significance of comprehensively discussing phenomena and issues that straddle both macro- and micro-aspects has been emphasized [3]. We turn our attention to the cardiovascular field in Japan where medical expenses form a large part of the total national medical expenses. Not so long ago, circulatory diseases accounted for the largest share of medical expenses, which increased year by year, accounting for 19.7 % of national health expenditure in 2016 [4]. In the last 5-year period (2016–2020), the number of PCI procedures increased by 0.9 % annually (adjustment: the number of medical facilities, emergency PCI: 3.2 %) [5]. High-profile cost-effectiveness evidence could be applied to macro- and micro-issues in this area to ensure the sustainability of systems and adequacy of resource allocation. In fact, there are several reports, mainly from outside Japan, on the medical economics of the treatment of ischemic heart disease, which is the main target of PCI, as described later.

Based on the above background, an international comparison of medical economic macro analyses related to the treatment of acute myocardial infarction (AMI) is presented to provide an overview for discussing the cost-effectiveness of PCI. Fig. 1 shows a simplified overview of the macro performance (cost-effectiveness) of AMI mortality and medical costs. A survey conducted in 2020 covered twenty-eight countries involved in the Organization for Economic Cooperation and Development for which data aggregation was possible [7]. Cases in the target population were aged 45 years and older and adjusted for sex and age. Mortality was defined as the 30-day mortality connecting medical facilities along treatment. In Japan, the consolidation of medical facilities was unknown. Medical costs were scored relative to associated hospital costs across the population (100 scale). The cost data were corrected by the Purchasing Power Parity [8]. The countries located in the lower left of the approximation curve ($r = -0.58$, $p < 0.01$) in the figure have low mortality rates and low costs, so they are interpreted as having excellent cost-effectiveness. Considering the level of performance in the world, Japan is presumed to have some room for improvement.

From the above brief analysis, it can be seen that the performance of AMI treatment varies greatly between countries. Factors such as country-specific demographics, health policies, medical systems, and living environments can be imagined as contributing background factors. In addition to the pathophysiological composition, it is speculated that differences in standard clinical protocols also play a large role. For example, when comparing Japan and the USA, there is a report that the rate of elective PCI in Japan is more than double that in the USA (72.7 % vs. 33.8 %, $p < 0.001$) [9]. In addition, the noninvasive stress test implementation rate for stable angina pectoris is significantly lower in Japan than in the USA (15.2 % vs. 55.3 %; $p < 0.001$) [9]. Further

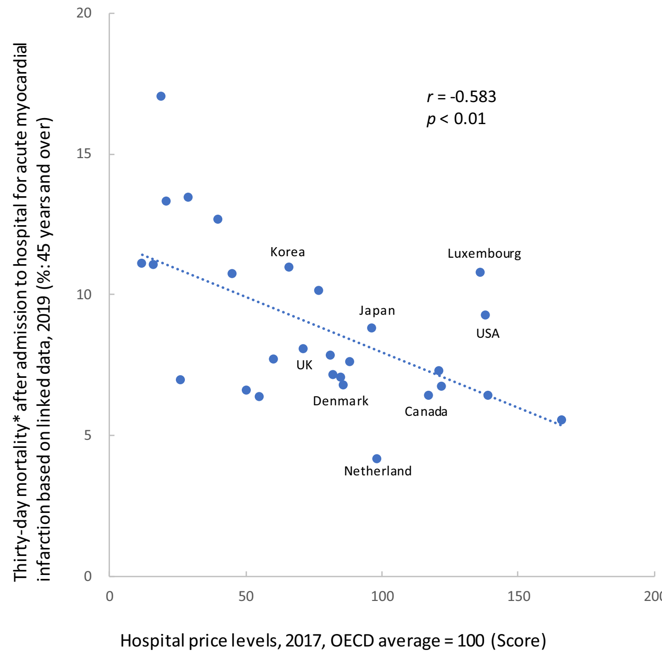

Fig. 1. Overview of medical economic performance based on acute myocardial infarction mortality and hospitalization costs (data obtained from countries involved in the Organization for Economic Cooperation and Development).
Healthcare systems generally tend to improve clinical performance as the level of healthcare resource consumption increases. In this graph, when sorted by cost effectiveness, the countries located in the lower left have good medical economy. Individual country policies should consider shifting below the asymptote, which is the global average, to ensure the sustainability of the health-care system. Japanese mortality data were modified by the information of The Japanese Circulation Society [5]. Netherlands mortality data were corrected in the related report [6].
(*) Age-sex standardised rate per 100 admissions aged 45 years and over.
a: PPPs are estimated predominantly by using salaries of medical and non-medical staff (input method).
b: 1. Data do not include deaths outside acute care hospitals.
(Source) OECD Health Statistics 2021.

investigation is required to determine the extent to which these trends affect the macro performance of AMI treatment as described above. However, it is easy to imagine that the clinical characteristics affect the medical economic outcome of the area concerned. In addition, the cost-effectiveness performance of individual medical technologies, particularly that of PCI, which is at the center of intervention, is an important determinant of the medical economy of the area.

Methods: theory and method of cost-effectiveness evaluation

In recent years, it has been expected to illustrate the medical value in response to the social proposition of promoting medical innovation and sustaining a universal health insurance system [3,10]. It is inferred that the role of cost-effectiveness can be positioned as part of this measure. Generally, in microeconomics, price is converged, and efficiency is maximized based on supply and demand equilibrium, based on utility theory. However, while incorporating the perspective of equity with the goal of maximizing the well-being of the population, medical value discusses the balance between the patient's utility value (preference, willingness to pay) and medical finance (income redistribution, financial balance) from the viewpoint of public interest (Fig. 2) [3]. As such, this value advocates enhancing the balance between benefits and costs per health program unit, interweaving the relationship between the individual and society. As a result, if utility is maximized within a certain budget, the higher the cost-effectiveness, the higher the utility of the group as a whole, and the higher the real “value” of

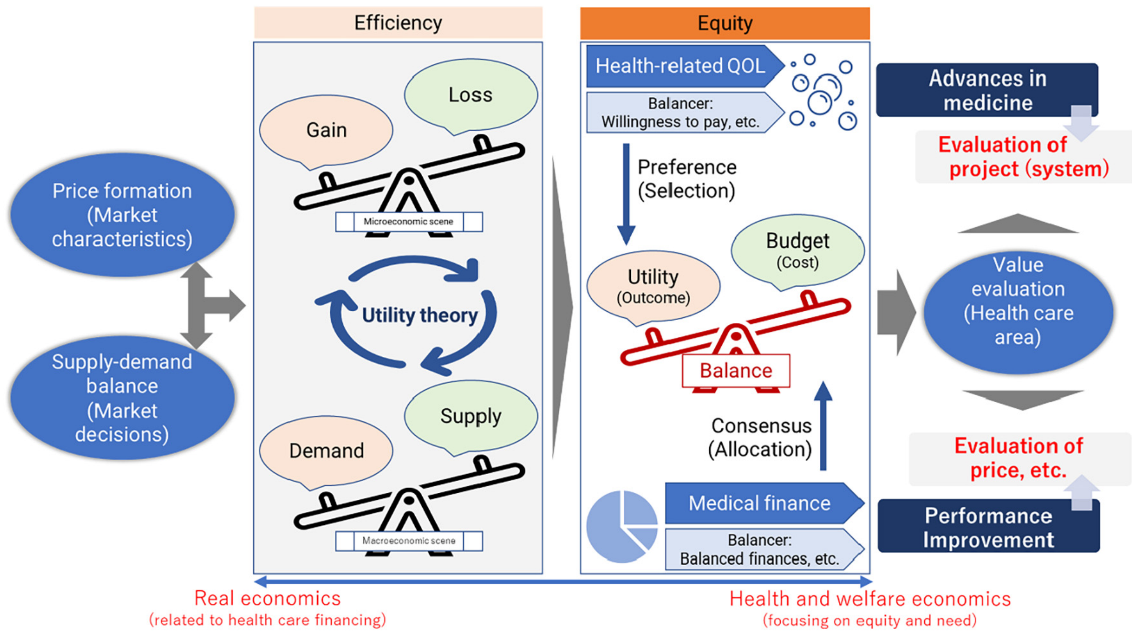

Fig. 2. The concept of value evaluation of health care based on utility theory and cost-effectiveness considering welfare economics.
Medical value can be discussed, albeit in a limited way, by combining marginal utility theory and cost-effectiveness evaluation. Based on this, we will examine three important and closely related perspectives involved in the development of the medical system in the future: An examination of universal health coverage in the light of socio-economic factors, the significance of citizens' value in resource allocation, and price formation considering the economic burden of patients. For example, high expectations for cost-utility evidence can be applied to macro- and micro-issues to ensure the sustainability of the system and the appropriateness of resource allocation [2].

stakeholders. Compared to discussing conceptual value, this approach is relatively possible in considering the relationship with the real economy and general value, and therefore, suitable for examining medical treatment prices in the public medical field.

The value of health services in Japan, which is a public sector, can be indirectly evaluated by applying marginal utility theory and preference-based scales under conditions and objectives different from those in the private sector [11]. Incidentally, in the medical field, a method for measuring and analyzing a patient's utility value is being developed as a type of health-related quality of life. Cost-utility analysis (CUA) is an application of this concept to cost-effectiveness analysis (CEA). Based on this, when a utility function is applied to cost-effectiveness, medical value is calculated as “resource consumption (mainly direct medical costs)/health recovery (patient outcomes such as utility)” [12]. In addition, one of the outcomes is a global index called quality-adjusted life years (QALYs). This is a concept that integrates a patient's utility value and years of life, and it is an index that discusses both quantitative (life prognosis) and qualitative outcomes (QOL) [12]. These concepts are also maintained as guidelines in the cardiovascular field by organizations such as the American Heart Association in the USA [13,14].

This cost-effectiveness has been introduced into the medical insurance system in Japan since 2019, and it is used to verify the balance of clinical usefulness and economic burden of drugs and medical devices with high public prices and huge market size. In this cost-effectiveness assessment, we generally discuss the level of performance (e.g. slope). When the dimensions and levels of effectiveness and cost differ between the selected clinical techniques in health technology assessments, the Incremental Cost-Effectiveness Ratio (ICER) is selected, which discusses the ratio of additional benefit to increased cost (the so-called ratio of difference) [15]. Based on the consensus of the national economic burden calculated by willingness to pay and gross domestic product, the decision criteria are the allowable amount of about 5 million to 7.5 million yen per QALY acquisition [16]. This approach demands attention to analytical certainty and outcome sensitivity. The price adjustments for expensive medical technology (e.g. transcatheter aortic valve implantation, chimeric antigen receptor T-cell therapy) to which this evaluation was applied are still fresh in our minds.

ICER can be viewed as a “yardstick” for strictly judging “whether cost-effectiveness is superior or inferior.” Since the standpoint of analysis is generally a social point of view, the “cost” of treatment materials is sorted according to the standard of “medical fee claim (public price)” [11]. Usually, this cost discusses the cumulative consumption of medical resources such as examination/diagnosis, treatment/surgery, hospitalization, rehabilitation, and medicines/medical devices. As for “effectiveness”, clinical indices, life prognosis and patient-subjective outcomes (QOL and QALY mentioned above) are selected. QALY is quantified as 1 QALY for 1-year survival in perfect health and 0 QALY for death. The formula for ICER is the difference between the cost (b) of similar technology β and the cost (a) of new medical technology α [that is, (a–b)] divided by the difference between the effectiveness (B) of similar technology β and the effectiveness (A) of new medical technology α [that is, (A–B)] (Fig. 3) [13,16,17]. This can be expressed, so to speak, as “how much additional cost is required to obtain a high additional effect?” When utility (QALY) is selected as the outcome, it is sometimes referred to as Incremental Cost-Utility Ratio (ICUR).

Based on the above, we collected previous research examples of cost-effectiveness related to PCI. The target databases were MEDLINE and EMBASE. The survey period was from January 2010 to August 2022. The articles included were original articles and systematic reviews. The search queries were [PCI OR percutaneous transluminal coronary angioplasty (PTCA) AND cost-effectiveness OR health economy]. Due to the paucity of studies, constraints of evidence level were not imposed. However, reports from Japan were prioritized over those from other countries. Additionally, field studies were prioritized over simulation studies as simulation studies are difficult to categorize into an evidence level [18]. Moreover, when sorting the literature, priority was given to the most recent reports. By the way, the first general report of the cost-effectiveness of revascularization was the ICUR study in CABG in 1981 [14]. Henceforth, in the present paper, we standardized ICUR to ICER. This paper organized stable coronary artery diseases and chronic coronary syndrome respecting the original notation of each report.

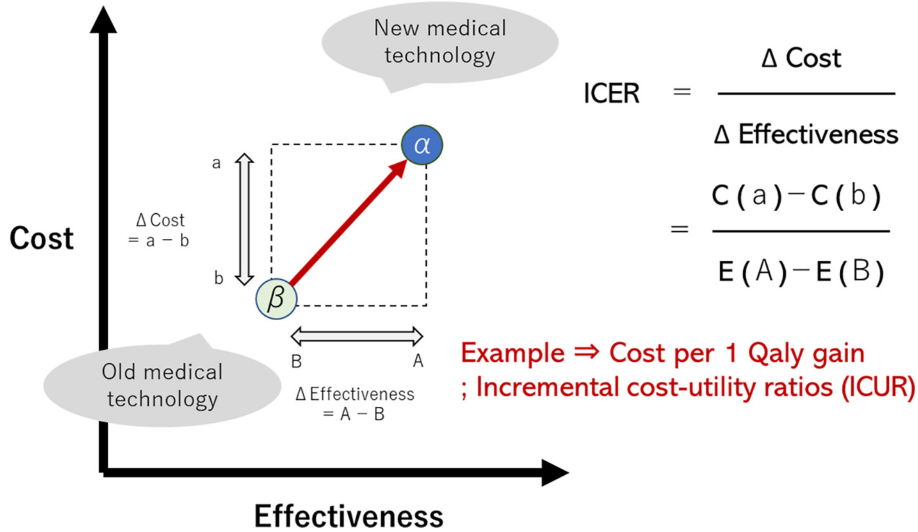

Fig. 3. The concept and calculation method of the Incremental Cost-Effectiveness Ratio (ICER).
In general, the level of cost-effectiveness is expressed by the ICER. The ICER is compared to a predetermined threshold. If this value is less than the threshold, it is categorized as cost-effective, and not cost-effective otherwise. When the intervention is less expensive and more effective, it is categorized as dominant. When it is costlier and more effective, it is categorized as effective. If it is less expensive and effective, it is categorized as doubtful, and if it is costlier and less effective, it is categorized as inferior.

Results: cost-effectiveness trends of PCI

Standalone cost-effectiveness trends

PCI reduces mortality in ACS patients. Therefore, many guidelines recommend invasive therapy for all patients with ST-segment elevation myocardial infarction (STEMI) and most patients with non-ST-elevation ACS [19,20]. Currently, the proportion of elderly patients with ACS is increasing, and their management should be similar to that of younger patients. Therefore, considering its expanded use in the elderly, we introduce a recent report on the cost-effectiveness of PCI [21]. This paper is based on a project spanning six European countries (EUROTRACS: EUROpean Treatment & Reduction of Acute Coronary Syndrome cost analysis). This report was a modeling study (Markov model) based on the course of disease from first admission to death in ACS patients aged 75 years and older. The results suggest that, compared to the current clinical practice, broadening the PCI use in elderly ACS patients would be cost-effective across different healthcare systems in Europe, regardless of the selected strategy [21]. For example, ICER of providing PCI to all patients ranged from 2262.8 €/Qaly gained for German males to 6324.3 €/Qaly gained for Italian females. Increasing PCI use was cost-effective at a willingness-to-pay threshold of 30,000 €/Qaly gained for all scenarios in the six countries, in males and females. As described above, standalone cost-effectiveness of PCI tends to be relatively high among life-saving interventions for ACS patients.

Comparison of PCI and CABG

The Synergy Between Percutaneous Coronary Intervention With TAXUS and Cardiac Surgery (SYNTAX) trial demonstrated that in patients with three-vessel or left main coronary artery disease, CABG was associated with a lower rate of cardiovascular death, myocardial infarction, stroke, or repeat revascularization when compared to PCI with drug-eluting stents (DES) [22]. Based on this trend, there was a report of a cost-effectiveness analysis applying SYNTAX trial data [research design: randomized clinical trial (RCT), observation period: five years] [23]. Lifetime simulation results show an ICER of €5390/QALY in favor of CABG. However, DES-PCI was found to be economically dominant when compared to CABG in patients with a SYNTAX Score ≤22 or in those with left main artery disease (Fig. 4, Table 1). There is a similar report (ICER of CABG: 16,537 US$/QALY) related to the SYNTAX trial [24]. Based on data from the EXCEL trial, CABG was an economically savvy strategy over a lifetime horizon for patients with significant left main coronary artery disease (ICER: 44,235 US$/QALY) [25]. A systematic review of 16 papers published in 2016 found that CABG was more cost-effective in the long term than PCI for complex multivessel coronary artery disease [26]. The cost-effectiveness of PCI versus CABG differed according to several anatomic factors. In the analysis related to this theme, it is necessary to accumulate more evaluation results that incorporate a social perspective and a time range of a lifetime or 10 years or more while considering multifaceted influential factors. For

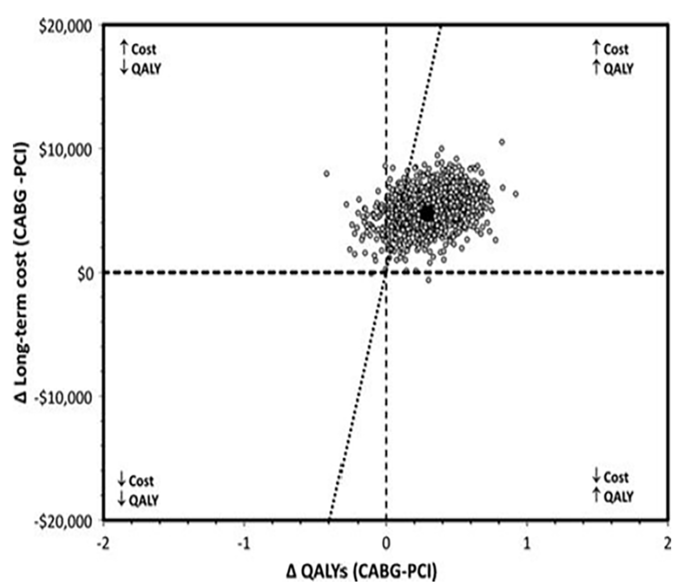

Fig. 4. Comparison of cost-effectiveness of percutaneous coronary intervention (PCI) and coronary artery bypass grafting (CABG).
Joint distribution of projected lifetime incremental costs and quality-adjusted life expectancy for CABG vs PCI based on bootstrap replication of the Synergy Between Percutaneous Coronary Intervention With TAXUS and Cardiac Surgery (SYNTAX) trial population plotted on the cost-effectiveness plane. The black circle represents the estimated mean values [incremental cost = $ 5081; incremental quality-adjusted life-year (QALY) = 0.307] [22].

Table 1
Cost-effectiveness comparison of percutaneous coronary intervention and coronary artery bypass grafting. Lifetime cost-effectiveness results for subgroups.
Source: Reference [23].

	Cost, $			QALYs			ICER, $/QALY	CABG Dominant, %	CABG Dominated, %	CABG < $50,000, %*
	CABG	PCI	Δ (95 % CI)	CABG	PCI	Δ (95 % CI)				
Age ≤60 y (n = 553)	105,305	101,926	3378 (−3261 to 9692)	14.28	13.95	0.32 (0.40 to 0.95)	10,488	7.7	11.1	72.3
Age 61–70 y (n = 586)	92,881	88,303	4578 (−1070 to 10,581)	10.55	10.21	0.34 (−0.44 to 1.00)	13,359	3.6	14.5	74
Age >70 y (n = 627)	80,810	73,555	7254 (1972 to 12,302)	7.19	6.97	0.21 (−0.51 to 0.84)	34,027	0.1	25.5	57.6
Diabetes mellitus (n = 494)	97,787	91,943	5843 (−378 to 12,214)	10.12	9.53	0.59 (−0.15 to 1.28)	9864	2.6	6.1	87.7
No diabetes mellitus (n = 1272)	90,383	85,644	4739 (908 to 8519)	10.68	10.52	0.16 (−0.323 to 0.606)	29,129	0.1	24.1	64.2
LM disease (n = 694)	93,732	86,114	7618 (2225 to 12,734)	9.94	10.233	−0.29 (−1.00 to 0.37)	PCI dominant	0	81.1	8.9
3-Vessel disease (n = 1072)	91,619	88,270	3350 (−673 to 7368)	10.92	10.24	0.68 (0.17 to 1.10)	4905	5.2	0.2	94.3
SYNTAX score ≤22 (n = 562)	95,624	92,582	3043 (−2826 to 9205)	10.97	11.17	−0.20 (−0.95 to 0.46)	PCI dominant	1.8	60.6	18.3
SYNTAX score 23–32 (n = 600)	87,747	83,540	4207 (−1432 to 9544)	10.29	10.18	0.114 (−0.60 to 0.79)	36,790	2	32.8	52.3
SYNTAX score ≥33 (n = 595)	94,309	86,384	7925 (2740 to 13,296)	10.36	9.4	0.96 (0.35 to 1.58)	8219	0.2	0.2	99.4
US patients (n = 241)	105,396	96,015	9382 (−1623 to 20,402)	10.84	10.05	0.79 (−0.30 to 1.78)	11,936	3.1	5.4	85.7
Non-US patients (n = 1525)	90,500	86,086	4414 (1027 to 7601)	10.5	10.27	0.24 (−0.20 to 0.65)	18,737	0.2	13.3	75.7

Costs and QALYs are discounted at 3 % per year. Δ indicates difference between CABG and PCI groups; CABG, coronary artery bypass grafting; CI, confidence interval; ICER, incremental cost-effectiveness ratio for coronary artery bypass grafting versus percutaneous coronary intervention; LM, left main; PCI, percutaneous coronary intervention; QALY, quality-adjusted life-year gained; and SYNTAX, Synergy Between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery.

* Probability that CABG is the preferred strategy at a societal ICER of $50,000 per QALY gained.

reference, the CULPRIT-SHOCK trial compared the medical economics of immediate multivessel PCI (MV-PCI) to culprit vessel only PCI (CO-PCI, with additional staged revascularization if indicated) [27,28]. The results showed that the lifelong CUA had an ICER (CO-PCI vs. MV-PCI) of 7010 €/QALY and a probability of >64 % that CO-PCI will be the most cost-effective strategy at a € 30,000 threshold.

Comparison of PCI and medical therapy

In the ORBITA trial (study design: RCT, observation period: 12 months) that compared anti-anginal therapy (200 adult patients with stable angina and angiographically severe single-vessel coronary artery disease) to PCI and to medical therapy (placebo group), the ICER (utility value conversion is model analysis) of the PCI group was £90,218/QALY (Table 2) [29]. This result exceeded the £30,000 threshold used by the UK National Institute for Health and Care Excellence when conducting health technology assessments, proving that PCI tended to be less cost-effective. Despite being a model study, there is a report in Japan that analyzes the cost-effectiveness of PCI compared to drug therapy for STEMI and angina pectoris [30]. According to this, the ICER of PCI in the STEMI group was 0.97 million yen/QALY, and the ICER of the angina pectoris group was 4.63 million yen/QALY, which was generally considered good. On the other hand, the ICER for asymptomatic patients was 23 million yen/QALY, which was considered as a very poor medical economic outcome (in Japan, the cost-effectiveness judgment standard in the public medical insurance system is 5 million to 7.5 million yen per 1 QALY gained [16]). A prospective observational study including patients with stable ischemic heart disease also showed that a cost-effectiveness analysis (10-year long-term simulation) of adding elective PCI compared to baseline (preoperative) treatment strategy formulation resulted in approximately 70,000 US$/QALY (probability expected value) [31]. According to a simulation report (time horizon: lifetime) in 2013 that evaluated the medical economics of PCI against medical therapy for the initial strategy in patients with stable coronary artery disease, DES-PCI was found to be highly cost-effective in the highest risk group which included those with diabetes with long lesions and small arteries (ICER: 18,826 US$/QALY) [32].

Other cost-effectiveness examples

We present a report on the cost-effectiveness analysis of PCI in terms of catheter approach and stent type. First, a database (Victorian Cardiac Outcomes Registry) study comparing the economics of transradial with transfemoral access PCI found that the radial access group had improved patient outcomes (mortality rate: 19 fewer per 1000) and significant cost savings (AU$ 1,214,688) as compared to the femoral access group [33]. Furthermore, according to a model analysis (observation period: two years) using data from the MATRIX trial for ACS, ICER for transradial access PCI improved by 11.9 QALY as compared to transfemoral access PCI, and AU$ 51,305 was saved, demonstrating good cost-effectiveness (Table 3) [34]. Next, we report on the cost-effectiveness studies of DES and bare-metal stents (BMS). According to a retrospective cohort study (database study, observation period: five years) in patients with coronary heart disease, DES-PCI (NT$ 238,394 per cardiovascular death or coronary event averted) was superior to BMS-PCI (NT$ 663,000), and it was more cost-effective [35]. Similarly, although there was no significant difference in the target vessel revascularization/target lesion revascularization rate and EQ visual analog scale/Utility score, the ICER of DES-PCI was HK$ 187,000/QALY, suggesting that DES was economically superior, especially for STEMI ACS [36]. For reference, we introduce a modeling study that was constructed to compare the cost-effectiveness of intravascular ultrasound (IVUS) to angiography guidance [37,38]. Use of IVUS guidance during PCI is likely to be more cost-effective as compared to angiography guidance alone in patients with left main and complex coronary artery lesions (ICER: 36,651 AU$/QALY).

Discussion: measures to improve the health economics of PCI

In order to improve the health economics of interventional procedures, it is imperative that the populations under consideration for treatment be directed toward optimization of cases. In other words, the process of selecting cases for which additional usefulness can be expected (including informed consent) is as important as the process of treatment quality control (including treatment planning), in improving the performance (cost-effectiveness) of interventional procedures. In this way, it is desired that diagnosis, treatment as well as support

Table 2
Cost-effectiveness comparison of percutaneous coronary intervention and medical therapy. Cost-effectiveness results for a cohort of 1000 patients.
Source: Reference [29].

Treatment	Total costs	Total QALYs	Cost difference	QALY difference	ICER
Placebo	£410,405	796.092			
PCI	£1,995,418	813.661	£1,585,012	17.569	£90218[a]

ICER, incremental cost-effectiveness ratio; PCI, percutaneous coronary intervention; QALYs, quality-adjusted life-years.

[a] ICER calculated prior to rounding.

Table 3
Cost-effectiveness comparison of transradial access percutaneous coronary intervention (PCI) and transfemoral access PCI. Results of the base-case analyses.
Source: Reference [34].

Parameter	Treatment arm		Difference
	TRA-PCI	TFA-PCI	
Key acute clinical events			
Non-fatal CVD	127.6	133.1	−5.5
Bleeding	13.1	20.8	−7.7
Fatal CVD	29.8	42.5	−12.7
Clinical effectiveness parameters (discounted)			
Total life years	1877.10	1863.70	13.4
Total QALYs	1488.90	1477.10	11.9
Cost parameters (discounted)			
Index PCI costs	$14,141,798	$14,141,798	$0
Acute event costs	$1,598,621	$1,729,784	−$131,163
Annual disease costs	$10,804,724	$10,724,865	$79,859
Total costs	$26,545,143	$26,596,448	−$51,305
Cost-effectiveness parameters			
Cost per YoLS	–	–	−$3822
Cost per QALY gained	–	–	−$4325

CVD, cardiovascular disease; QALY, quality-adjusted life year; PCI, percutaneous coronary intervention; TFA-PCI, transfemoral access-percutaneous coronary intervention; TRA-PCI, transradial access-percutaneous coronary intervention; YoLS, year of life saved. All costs are presented in 2021 Australian dollars (AU $).

programs such as follow-up (prevention of recurrence and aggravation), are organically linked in order to improve the medical economics of health programs and medical technology in a certain group. This concept is positioned in the clinical value chain as it synergistically enhances the individual value of diagnosis and treatment. For example, in a condition such as heart failure that repeats acute and chronic phases, early examination/diagnosis and treatment strategies may affect not only the prognosis of the target treatment cycle, but also the medical economics in the patient's journey (as shown in the lifetime analysis illustrated in the earlier section). Looking at these from a broad perspective, it is understood that they overlap with the concepts of Appropriate Use Criteria (AUC) and Universal Health Coverage (UHC), which have been the recent focus of attention in relation to the Sustainable Development Goals (SDGs) [39,40]. In order to further improve the social significance of PCI in the future, it is necessary to aim for harmony between clinical practice and economics as well as to promote treatment strategies from the above-mentioned perspective.

Therefore, we will attempt to organize trends in the treatment selection related to evaluation of examinations and diagnoses, with a focus on the field of chronic coronary syndrome (CCS). The COURAGE trial found that PCI did not reduce mortality/AMI when compared to optimal medical therapy (OMT) in patients with stable coronary artery disease, thereby questioning the efficacy of revascularization [41,42]. The ORBITA trial also reported that PCI did not improve exercise time as compared to a placebo procedure in patients with stable angina pectoris receiving OMT [29,43]. On the other hand, the FAME 2 trial showed that fractional flow reserve-guided PCI reduced events as compared to drug therapy alone in patients with stable coronary artery disease [44,45]. Against this background, from 2018, the diagnosis of functional ischemia has become a mandatory requirement for medical fee calculation in Japan as well. Recently, the ISCHEMIA trial, which compared early invasive treatment with conservative treatment strategies managed with pharmacotherapy in patients with moderate or greater ischemia, found that invasive treatment strategies were associated with cardiovascular death, MI, hospitalization for unstable angina/heart failure, and postcardiac arrest composite events [45,46]. From the above, it is predicted that a combination of patient selection and clinical intervention will influence the cost-effectiveness of PCI. Therefore, we will present reports from Japan on medical economic analysis of examinations and diagnoses regarding PCI.

Firstly, we focus on a Japanese report that evaluated the medical economic value of myocardial ischemia assessment for CCS patients in the real world [47]. This multicenter long-term longitudinal cohort study applied medical big data (including defer and revascularization cases). The analysis found that major adverse cardiovascular events as well as the medical costs and cost-effectiveness of the myocardial ischemia assessment group (including cases with combined coronary computed tomography angiography) outperformed the anatomic assessment group (CEA: 2431 US$/LY vs. 2902 US$/LY, $p = 0.043$) (Table 4). The number of coronary stents placed during PCI intervention was significantly lower in the myocardial ischemia assessment group (1.91 vs. 1.17, $p = 0.001$). This study also revealed the social importance of medical treatment selection based on information about myocardial ischemia. Secondly, we look at a study that aimed to evaluate the cost-effectiveness of follow-up invasive coronary angiography (FUICA) after PCI [48]. This retrospective long-term longitudinal cohort study showed that the cumulative three-year incidence of the primary endpoint was 5.3 % in the angiographic follow-up group and 4.7 % in the clinical follow-up alone group (hazard ratio: 1.02; $p = 0.98$). The total incremental cost at the three-year endpoint in the angiographic follow-up group was $ 1873 higher than that in the clinical follow-up

Table 4
Health economics-based verification of functional myocardial ischemia evaluation of stable coronary artery disease in Japan: a long-term longitudinal study using propensity score matching. Comparison of the medical costs, life years, and cost-effective analysis in the functional group and the anatomical group (by category).
Source: Reference [47].

	A: Over all			B: Non-invasive examination			C: Invasive examination		
	Anatomical group (n = 699)	Functional group (n = 699)	P value	CTA group (n = 402)	SPECT group (n = 402)	P value	CAG group (n = 261)	FFR/SPECT group (n = 261)	P value
	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	
Life years (LYs, years)	2.663 ± 0.560	2.666 ± 0.543	0.916	2.619 ± 0.562	2.675 ± 0.525	0.146	2.695 ± 0.544	2.652 ± 0.561	0.383
Total medical costs (US$)	7038 ± 11,397	6248 ± 8653	0.144	5149 ± 8535	4059 ± 5957	0.036	13,587 ± 16,371	9485 ± 11,190	0.001
Hospitalization costs (US$)	4430 ± 10,644	3105 ± 7588	0.007	2592 ± 7791	1197 ± 4964	0.003	10,350 ± 16,157	6228 ± 10,024	0.001
[Details]									
Medical care (US$)	2141 ± 5768	1705 ± 4472	0.115	961 ± 3103	602 ± 2723	0.082	6003 ± 9387	3488 ± 6057	<0.001
Medication (US$)	287 ± 1186	339 ± 883	0.356	130 ± 1164	112 ± 495	0.777	833 ± 1935	688 ± 1241	0.309
Special treatment materials (US$)	2002 ± 5392	1061 ± 3897	<0.001	1501 ± 4648	483 ± 2354	<0.001	3514 ± 6648	2052 ± 5550	0.007
Outpatient costs (US$)	2608 ± 2905	3143 ± 3205	0.001	2557 ± 2508	2862 ± 2842	0.107	3237 ± 3319	3257 ± 3310	0.946
[Details]									
Medical care (US$)	1080 ± 817	1290 ± 946	<0.001	1086 ± 794	1252 ± 846	0.004	1143 ± 859	1229 ± 866	0.254
Medication (US$)	1528 ± 2418	1853 ± 2659	0.017	1471 ± 2073	1610 ± 2371	0.376	2094 ± 2839	2028 ± 2856	0.789
CEA (US$/LY)	2902 ± 5115	2431 ± 3433	0.043	2120 ± 3750	1551 ± 2188	0.009	5404 ± 7183	3701 ± 4511	0.001

CTA, coronary computed tomography angiography; SPECT, cardiac single-photon emission computed tomography; CAG, coronary angiography; FFR, coronary fractional flow reserve; SD, standard deviation; CEA, cost-effective analysis.

alone group (US$ 8947 vs. US$ 7073; p ≤ 0.001). FUICA increased costs while not improving clinical benefits. As a result, FUICA was not economically more attractive than clinical follow-up alone. It should be noted that these studies have some limitations in study design and data type, as well as a degree of uncertainty in the study results.

Summary: as conclusion

As a result of investigating the current cost-effectiveness level of PCI, the following findings were clarified. The macro medical economics of AMI treatment, which is the main target of PCI, was generally at an average level compared to other countries, but there is room for further improvement in Japan's performance. Appropriate medical intervention is essential for this improvement approach, as is the appropriate selection of cost-effective medical technology. The standalone cost-effectiveness evaluation of PCI tends to be relatively high among life-saving interventions for ACS patients. Revascularization in a population with multivessel coronary artery disease showed that CABG tended to be more cost-effective than PCI in the long-term setting. On the other hand, PCI has been suggested to be more cost-effective in patients with SYNTAX Score ≤22 or left main coronary artery disease. A cost-effectiveness report for stable angina pectoris patients did not support PCI performance over medical therapy. In addition, some reports showing the medical economic superiority of myocardial ischemia evaluation and IVUS guidance during PCI have predicted that active selection will contribute to the improvement of the overall cost-effectiveness of PCI. In order to further improve the social significance (value) of PCI in the future, it is necessary to aim for harmony between clinical practice and health economics.

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Data availability

The deidentified participant data will not be shared because the data presented in this review paper were all cited.

Declaration of competing interest

There are no conflicts of interest to declare.

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