Five-Year Cost-effectiveness of the Multidisciplinary Risk Assessment and Management Programme–Diabetes Mellitus (RAMP-DM)

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OBJECTIVE

To estimate the cost-effectiveness of the multidisciplinary Risk Assessment and Management Programme–Diabetes Mellitus (RAMP-DM) in primary care patients with type 2 diabetes in comparison with usual primary care in a cohort with 5 years' follow-up.

RESEARCH DESIGN AND METHODS

We conducted a prospective cohort study among 17,140 propensity score–matched participants in RAMP-DM and those under usual primary care. The effectiveness measures were cumulative incidences of complications and all-cause mortality over 5 years. In a bottom-up approach, we estimated the program costs of RAMP-DM and health service utilization from the public health service provider's perspective. The RAMP-DM program costs included the setup costs, ongoing intervention costs, and central administrative costs. We calculated the incremental cost-effectiveness ratio by dividing the incremental costs by the incremental effectiveness of the RAMP-DM group compared with those of the usual-care group.

RESULTS

There were significantly lower cumulative incidences of individual on any complications (15.34% vs. 28.65%, $P < 0.001$) and all-cause mortality (7.96% vs. 21.35%, $P < 0.001$) in the RAMP-DM group compared with the usual-care group. The mean program cost of RAMP-DM was 157 U.S. dollars (range 66–209) per participant over 5 years. The costs of health service utilization among participants in RAMP-DM group was 7,451 USD less than that of the usual-care group, resulting in a net savings of 7,294 USD per individual.

CONCLUSIONS

RAMP-DM added to usual primary care was a cost-saving intervention in managing diabetes in patients over 5 years. These findings support the integration of RAMP-DM as part of routine primary care for all patients with diabetes.

The prevalence of diabetes is increasing globally. The latest estimation shows that there were 415 million people with diabetes all over the world by 2015, and the number is estimated to climb to 642 million by 2040 (1). China is among the countries with the highest diabetes prevalence: 11.6% among the adult population (2). Management of diabetes and diabetes-related complications posts a huge medical, social, and financial burden. It cost ~727 billion USD in total to manage diabetes in 2015, taking

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up 12% of the total global health care expenditure (1). In view of the rising prevalence and giant financial burden of diabetes, it is imperative to implement effective and inexpensive interventions to enable cost-effective management of diabetes in patients.

In recent years, guidelines have recommended risk stratification–based management (3–5), setting personalized treatment goals based on patients' individual cardiovascular risks. For implementation of risk stratification–based management, a multidisciplinary team is required, including nurses, doctors, and allied health professionals. Accumulating evidence shows that multidisciplinary interventions can improve blood glucose control (6–9) and reduce complications in people with diabetes (10).

There are few studies on the cost-effectiveness of a multidisciplinary diabetes management program. Previous studies found that multidisciplinary interventions that included risk factor screening, risk stratification, and both nurse and doctor interventions cost 18–7,723 U.S. dollars (USD) per unit reduction in HbA_{1c} over 6–12 months of intervention (11,12). Katon et al. (13) estimated the cost-effectiveness of a physician-supervised nurse care multidisciplinary program for people with diabetes with coexisting coronary heart disease and depression over 24 months' intervention. This study found this intervention to be cost saving in terms of gain of 114 additional depression-free days for and lower outpatient costs in the intervention group. Only one study estimated the cost-effectiveness of multidisciplinary interventions (Anglo-Danish-Dutch Study of Intensive Treatment in People with Screen Detected Diabetes in Primary Care [ADDITION]-UK) by improvement in the incidences of cardiovascular disease (CVD) events and found no significant effectiveness owing to insufficient time of follow-up (14).

The Hong Kong Hospital Authority (HA), the main public health service provider, has launched the multidisciplinary Risk Assessment and Management Programme–Diabetes Mellitus (RAMP-DM) in Hong Kong public general outpatient clinics since August 2009 to enhance the care of patients with type 2 diabetes in primary care setting. Previous studies found that, compared with usual primary care, RAMP-DM was effective in reducing both macrovascular and microvascular complications and mortality over 1, 3, and 5 years' intervention (15–18).

There is a lack of evidence on the cost-effectiveness of a risk stratification–based multidisciplinary diabetes-management program. This study aimed at evaluating the cost-effectiveness of RAMP-DM added to usual primary care compared with usual primary care only in a cohort with five years' follow-up, using empirical cost and effectiveness data.

RESEARCH DESIGN AND METHODS

RAMP-DM Intervention

For enhancement of the primary care of people with DM, HA launched RAMP-DM, a territory-wide primary care service since August 2009. The details of the program have previously been reported (19). In brief, all the enrolled participants would undergo an intake assessment, which was a comprehensive risk assessment including measurement of risk factors for cardiovascular and renal complications and eye and foot assessment. The case manager, an advanced practice nurse, would review the examinations results, assess the cardiovascular risks, and stratify participants into risk groups ("very high," "high," "medium," and "low") according to the modified Joint Asia Diabetes Evaluation cardiovascular risk stratification flowchart (20). The participants were then assigned to receive appropriate interventions and education provided by a team of multidisciplinary health care professionals, including Associate Consultants in family medicine (AC intervention), registered nurses, advanced practice nurses (nurse intervention), and allied health professionals, according to stratified risk level and HbA_{1c} level. Based on different risk levels, some RAMP-DM participants would have an annual full risk factor screening and intake assessment and others would have the full assessment every 2–3 years with an annual blood test and follow-up by their primary care doctors. In other words, RAMP-DM is an additional intervention apart from usual primary care for RAMP-DM participants. The details of RAMP-DM intervention are illustrated in Supplementary Fig. 1.

People with diabetes under usual primary care continued to be managed by their primary care doctors without risk assessment and stratification. They were also eligible for referral to allied health professionals at their doctors' discretion.

Subjects

From 1 August 2009 to 30 June 2011, a total of 70,041 people aged 18 years or older with diabetes enrolled in RAMP-DM. We identified 35,950 people with diabetes, who had not enrolled in RAMP-DM by 30 November 2015, as potential participants for the usual-care group. After exclusion of 13,573 case subjects (7,101 in the RAMP-DM group and 6,472 in the usual-care group) with existing complications (including CVD, end-stage renal disease, diabetic retinopathy, blindness, or neuropathy) at baseline and 21,986 case subjects (1,166 in the RAMP-DM group and 20,820 in the usual-care group) with incomplete baseline data, there were 61,774 and 8,658 subjects in the RAMP-DM and usual-care groups, respectively. For elimination of selection bias, the study sample was further refined using propensity score matching (Supplementary Table 2). Finally, a total of 8,570 RAMP-DM participants and the same number of propensity score–matched usual-care subjects were included in the analysis. All subjects were observed until a study end point occurred: death or the last recorded date of service—whichever came first.

Ethics approval of the current study was granted by the institutional review board of the University of Hong Kong/HA.

Outcome Measures

The effectiveness of RAMP-DM was measured by *1*) the number of diabetes-related complications reduced by RAMP-DM during the 5-year study period and *2*) the number needed to treat (NNT) to reduce one diabetes-related complication. The NNT is an important measure of effectiveness in health economic evaluations. It is calculated as the inverse of the absolute risk reduction (21). The NNT is interpreted as the average number of patients needed to treat in order to prevent one unwanted outcomes. The lower the NTT, the more effective the intervention.

The incremental cost-effectiveness ratio (ICER) was the ratio of the incremental costs of the RAMP-DM group over the incremental effectiveness. In this analysis, the ICER referred to the cost per diabetes-related complication reduced by RAMP-DM.

Costs of RAMP-DM

This study estimated the costs from the public health service provider's perspective,

including all the public direct medical costs incurred by the study subjects.

An in-depth cost analysis of RAMP-DM was conducted by the bottom-up approach. The cost of RAMP-DM was divided into three components: *1*) setup costs, *2*) ongoing intervention costs, and *3*) central administrative costs. For acquisition of the cost information for *1* and *2*, two sets of cost questionnaires were used to collect data at the cluster and clinic levels, respectively. The data were collected from all seven clusters of the HA and two randomly selected clinics from each cluster. The cluster and clinic questionnaires collected resources used for the RAMP-DM accrued in the cluster and clinic, respectively, since its setup in 2009/2010 to the 2011/2012 financial year. Part *3*, central administration cost, was collected from the HA Head Office Finances Office.

Setup Costs of RAMP-DM

Setup costs of RAMP-DM referred to one-off expenses incurred in the course of setting up the program. These included costs related to staff training, additional equipment, information technology (IT), and infrastructure reported by the clusters that are responsible for the purchasing and staff training of the clinics.

By definition, the setup costs are fixed costs that do not vary with the number of subjects enrolled into the program over time. In other words, with all these investments, the clusters supposedly would have the capacity to manage all the eligible patients for RAMP-DM. Based on this, the per-subject setup costs were calculated by dividing the total expenditure accrued during the 3-year study period from 2009 to 2012 by the number of patients with diabetes in the respective cluster during this period. The numbers of people with DM for each cluster were extracted from the Clinical Management System of HA.

The training-related portion of staff salaries was calculated by dividing monthly RAMP-related training time by monthly working hours. The working hours of a full-time–equivalent HA staff are 39 h/week. Monthly salaries of the exact staff grades were provided by HA.

Equipment cost was defined as the expenditure on any additional medical equipment for setting up RAMP-DM. Other costs referred to items that were not prespecified in the questionnaire (e.g., furniture, stationary) that were incurred for setting up RAMP-DM.

Investment on IT or infrastructure, for example, for the development of an e-portal system for data collection and management was collected from the HA Head Office and was assumed to be equally distributed among the seven clusters.

RAMP-DM Ongoing Operation Costs

Ongoing costs referred to the recurrent costs for the program's operations and maintenance, including costs of staff and consumables. The information on resource usage and numbers of each RAMP-DM intervention session per month, the number and rank of staff involved in each session, number of patients served in each session, and general expenses related to RAMP-DM per month, in the 2011/2012 financial year, were collected. The costs for each type of RAMP-DM sessions, including intake assessment, nurse intervention, and AC intervention were calculated.

The monthly cost of administrative and supportive staff required to assist with handling the program logistics for each type of session was collected. The staff cost per intervention was calculated by dividing the monthly staff cost by the total number of RAMP-DM interventions conducted per month.

The unit cost per patient served for each type of RAMP-DM intervention was the sum of all the costs of clinical staff, administrative/supportive staff, and resource usage. To convert the unit cost per patient served into per-subject costs (each enrolled subject was not necessarily served by all types of RAMP-DM intervention), we multiplied the unit cost per patient served by the average number of each intervention each RAMP-DM subject received.

Central Administrative Cost

The central administrative cost of RAMP-DM incurred in the period 2009–2012 was collected from the Finances Office of the HA through the Statistics Team. The per-subject cost equaled the total central administrative cost divided by the total number of DM subjects within this period.

Costs of Public Health Service Utilization

Health service utilization rates of the study participants during the follow-up period were extracted from the HA Clinical Management System, including general outpatient clinic attendance, specialist outpatient clinic attendance, allied health professional attendances, A&E (Accident & Emergency) attendance, and inpatient length of stay. According to the policy of the HK Special Administrative Region (HKSAR) government, noneligible patients are charged on a cost-recovery basis. The charges for noneligible patients published in the 2013 HKSAR Government Gazette and Hospital Authority Ordinance (chapter 113) (Supplementary Table 1) were adopted as unit costs of the relevant health services. The unit costs are package costs that include all the medical service incurred during the visits, i.e., consultation, investigations, medication, and other treatment. The equation below was used to calculate the annual cost of each type of health service:

$$\text{Annual cost of health service utilization} = \sum \text{No. of health services} \times \text{unit cost of the service}$$

Cost-effectiveness Analysis

The empirical cost-and-effectiveness data observed during the 5 years' follow-up period were applied to the analysis. We did not discount the costs, since the unit costs of service in Hong Kong are updated every 10 years. The unit costs adopted in this study were published by HKSAR in 2013, which reflect current costs.

The total direct medical costs per subject in RAMP-DM were the sum of the RAMP-DM program costs and health services utilization costs. The costs per subject in the usual-care group only included the health services utilization costs.

The ICER was the ratio of the incremental costs of the RAMP-DM group over the incremental effectiveness compared with those of the usual-care group. In this analysis, the ICER referred to incremental cost per diabetes-related complication reduced by RAMP-DM. The intervention was considered cost saving if treatment of participants in RAMP-DM group cost less than in the usual-care group. One-way sensitivity analysis was conducted to test the uncertainties surrounding the RAMP-DM program cost per subject using the minimum-to-maximum values of costs reported by the seven HA clusters. All costs were originally calculated in Hong Kong dollars (HDK) and converted into USD for reporting (1 USD = 7.8 HKD).

Data Analysis

The basic characteristics between RAMP-DM and usual-care groups were compared by

χ^2 test, independent *t* test, or Wilcoxon rank-sum test, as appropriate. We used the χ^2 test to compare the clinical outcomes between the two groups. All the statistical analyses were conducted using STATA, version 13.0 (StataCorp, College Station, TX), and *P* values <0.05 were considered statistically significant.

RESULTS

Characteristics of Study Subjects

The basic characteristics of individuals in the study at baseline are shown in Supplementary Table 2. At baseline, all of the parameters had no statistically significant difference between the RAMP-DM and usual-care groups (Supplementary Table 2). The average age at baseline was 67 years, and 52% of the subjects were female.

Effectiveness of RAMP-DM

Compared with the usual-care group, participants in the RAMP-DM group had significantly lower cumulative incidence of any diabetes complication (15.34% vs. 28.65%, $P < 0.001$), all-cause mortality (7.96% vs. 21.35%, $P < 0.001$), and all the specific complications (Table 1). In the subgroup analysis, participants in RAMP-DM had lower cumulative incidences of all the complications and all-cause death in both male and female groups.

RAMP-DM Program Cost per Participant

Across all seven clusters, the average total setup cost was 5.27 USD per participant. The central administrative cost was 0.64 USD per participant. The average ongoing cost per intervention was estimated as 45.51 USD for the intake assessment, including 28.44 USD for nurse assessment and 17.05 USD for other health professionals (23.36 USD for the nurse intervention and 29.95 USD for the AC intervention) (Table 2).

Cost-effectiveness of RAMP-DM Over 5 Years

The average cost of annual RAMP-DM interventions was 59, 32, 25, 23, and 18 USD per subject in the first to fifth years, respectively (Table 3). The average number of each intervention per subject in each of the five years since enrollment into RAMP-DM is shown in Supplementary Table 3. In the first year, all subjects underwent an intake assessment when they enrolled, and approximately half had repeated intake assessments afterward.

The average annual costs of health service utilization in each year are shown in Supplementary Table 4. Within 1 year before the study baseline, the average annual costs of health care utilization were almost the same in the RAMP-DM group and usual-care group (1,347 vs. 1,359 USD). In the first year from baseline, the costs in the usual-care group increased sharply to 3,623 USD, and this trend continued in subsequent years. The annual health care costs in the RAMP-DM group also increased steadily over the 5 years but to a lower extent (Table 3).

As shown in Table 3, the total average cost for 5 years of the RAMP-DM program was 157 USD per subject (range 66–209). The health care utilization costs in the RAMP-DM group were consistently lower than those in the control group, which could be explained by the lower incidences of diabetes-related complications. Over 5 years, the usual-care group cost 7,451 USD more per subject on average for health care utilization. With both the RAMP-DM program cost and health care utilization costs taken into consideration, the RAMP-DM group direct public medical cost was 7,294 USD less per subject over 5 years than that for the usual-care group. Therefore, RAMP-DM was cost saving from the public health service provider's perspective.

Table 4 presents the incremental effectiveness of RAMP-DM for each of the study end points. In RAMP-DM, treatment of nine people with diabetes was needed to reduce one CVD complication and seven subjects to reduce one death from any causes compared with usual care. If we considered the program costs of RAMP-DM as additional costs while assuming the costs of health services were the same between the two groups, the program cost 1,304 USD (range 525–1,673) to reduce one complication and 1,141 USD (459–1,464) to reduce one death over 5 years.

CONCLUSIONS

Compared with the usual-care group, the RAMP-DM group had lower incidences of diabetes-related complications and all-cause mortality and cost 7,294 USD less per individual over the 5 years. When the program costs of RAMP-DM were considered as extra costs and when we assumed the costs of health service utilization to be the same between the two groups, RAMP-DM cost the public health provider 1,034 USD to avoid one complication and 1,141 USD to avoid one death case among people with diabetes. The economic analysis showed that the costs of RAMP-DM were offset by the reduction of health service utilization, especially the costs of hospitalization, which were largely attributed to the substantial reduction in the incidences of diabetes-related complications.

There were several factors attributed to the remarkable reduction in the incidences of complications in the RAMP-DM group. First, the multidisciplinary RAMP-DM team provided more education, including education on disease knowledge, self-care, and lifestyle, through nurse intervention, the Patient Empowerment Programme (PEP) (22), the smoking cessation, and a dietitian. Diabetes self-management education has been proved to prevent or delay the complication of diabetes (23–27); thus, the American Diabetes Association recommended standards for diabetes self-management education, which requires a multidisciplinary team, including physicians, nurses, a dietitian, and pharmacists, to provide structured, individual, and ongoing education to patients (28). The interventions of RAMP-DM met the recommended standards from the American Diabetes Association. Second, the risk stratification might also have a positive impact on improving patients' consciousness of health and motivating them to change lifestyles. The National Diabetes Prevention Program (DPP) found that structured lifestyle change programs significantly increased the proportion of people reaching body weight and physical activity targets among those at risks of diabetes (29). Third, risk-stratification management can also raise doctors' awareness, thereby leading them to offer more intensive management of high-risk patients. Structured risk assessment improved adherence to recommendations on annual assessment to detect reversible risk factors early, e.g., hypertension and hyperlipidemia, so that timely interventions could be given to prevent further deterioration.

This study was the first in-depth cost-effectiveness analysis of a systematic multidisciplinary risk stratification, comprehensive complication screening, and whole-person management. However, it was difficult to conduct a randomized control trial owing to the service nature of the RAMP-DM. The results should be interpreted with caution that the findings might be due to some unobserved confounders.

Table 1—Five-year cumulative incidences of diabetes-related complications and death

	Events over 5 years				
	RAMP-DM		Usual care		
	n	%	*n*	%	*P*
Overall (RAMP-DM = 8,570, usual care = 8,570)					
Any complication	1,315	15.34	2,455	28.65	<0.001
CVD	1,057	12.33	2,054	23.97	<0.001
AMI	240	2.80	529	6.17	<0.001
Other IHD	387	4.52	924	10.78	<0.001
Heart failure	291	3.40	693	8.09	<0.001
Stroke	445	5.19	727	8.48	<0.001
ESRD	391	4.56	696	8.12	<0.001
STDR	48	0.56	174	2.03	<0.001
All-cause death	682	7.96	1,830	21.35	<0.001
Male (RAMP-DM = 4,121, usual care = 4,075)					
Any complication	642	15.58	1,205	29.57	<0.001
CVD	510	12.38	983	24.12	<0.001
AMI	117	2.84	266	6.53	<0.001
Other IHD	183	4.44	497	12.20	<0.001
Heart failure	136	3.30	283	6.94	<0.001
Stroke	227	5.51	338	8.29	<0.001
ESRD	185	4.49	362	8.88	<0.001
STDR	30	0.73	111	2.72	<0.001
All-cause death	363	8.81	903	22.16	<0.001
Female (RAMP-DM = 4,449, usual care = 4,495)					
Any complication	673	15.13	1,250	27.93	<0.001
CVD	547	12.29	1,071	23.93	<0.001
AMI	123	2.76	263	5.88	<0.001
Other IHD	204	4.59	427	9.54	<0.001
Heart failure	155	3.48	410	9.16	<0.001
Stroke	218	4.90	389	8.69	<0.001
ESRD	206	4.63	334	7.46	<0.001
STDR	18	0.40	63	1.41	<0.001
All-cause death	319	7.17	927	20.72	<0.001

RAMP-DM = 39,474 person-years, usual care = 38,498 person-years. AMI, acute myocardial infarction; ESRD, end-stage renal disease; IHD, ischemic heart disease; STDR, sight-threatening diabetic retinopathy.

There have been few studies on the cost-effectiveness of a multidisciplinary diabetes-management program using empirical cost and observed complication incidences. Only ADDITION-UK reported empirical costs and observed complication incidences and mortality. ADDITION was a multidisciplinary program focusing on intensive treatment of cardiovascular risk factors among individuals with screen-detected DM (14). This study calculated the costs of delivering intervention and the routine cost of treating diabetes and diabetes-related complications from the perspective of the National Health Service. The effectiveness measure was quality-adjusted life years based on observed cardiovascular events after diagnosis of DM. The study found that the incremental costs of the intervention group ranged from £285.30 (369.87 USD) over a 1-year horizon to £934.90 (1,212.02 USD) over 5 years, but the intervention group did not show any health gain compared with usual care over 5 years. The study subjects screened positive people for diabetes at enrollment, and complications might take several years to develop. The intervention group began to show lower incidences of complications at the fourth year of follow-up but did not reach statistical significance at the end of the 5 years' follow-up period (30). Also, the risk factor screening and assessment were led by physicians in ADDITION, which was more expensive compared with appointing nurses as case managers in the RAMP-DM intervention. The mean duration of diabetes of individuals in our study was 8 years at baseline; thus, we observed a higher complication rate over 5 years' follow-up.

Table 2—Average RAMP-DM costs per subject

	HKD		USD	
Costs	Cost per subject	Range (min–max)	Cost per subject	Range (min–max)
Setup cost				
Training	6	1–11	0.79	0.13–1.41
Equipment	28	7–49	3.63	0.90–6.28
Others	1	0.3–2	0.10	0.04–0.26
IT/infrastructure	6	3–11	0.74	0.38–1.41
Subtotal	41	11–72	5.27	1.41–9.23
Central administrative	5	NA	0.64	NA
Ongoing costs				
Intake assessment	355	140–543	45.51	17.95–69.62
Nurse assessment	222	114–305	28.44	14.62–39.10
Other health professionals	133	26–238	17.05	3.33–30.51
Nurse intervention	182	101–362	23.36	12.95–46.41
AC intervention	234	106–369	29.95	13.59–47.31

Note: figures may not add up to the total as a result of rounding. max, maximum; min, minimum; NA, not applicable.

This study estimated the costs from the public health service provider's perspective; since the subjects were all regularly followed up at the HA public primary care clinics, the utilization and costs in private service should be minimal and the net saving of public medical costs in RAMP-DM subjects was unlikely due to shifting of service to the private sector. A previous study found that patients with diabetes who attended public diabetes clinics did not have any inpatient episode in private hospitals, and the cost of private outpatient service of these patients was only 6% of that of the public sector in Hong Kong (31). HA provides ~93% of the secondary and tertiary health care services in Hong Kong (32). Our previous study on direct medical costs of DM patients also found that 90% of the direct medical costs were public (33).

Cost-effectiveness studies on DM care could include the costs of all health service or only the costs of diabetes related health service (14,34–36). Our study

Table 3—Costs of RAMP-DM and usual-care groups over 5 years (*N* = 17,140)

	Cost per individual (USD)		
	RAMP-DM	Usual care	Difference
RAMP-DM setup cost, mean (range)	5 (1–9)	0	5
RAMP-DM administrative cost, mean	0.6		0.6
RAMP-DM intervention cost, mean (range)			
First year	59 (29–53)	0	59
Second year	32 (16–50)	0	32
Third year	25 (12–40)	0	25
Fourth year	23 (12–37)	0	23
Fifth year	18 (9–29)	0	18
Total costs of RAMP-DM program over 5 years	157 (66–209)	0	157
Health care utilization cost, mean ± SD			
First year	1,945 ± 5,978	3,623 ± 9,064	−1,678
Second year	2,293 ± 8,098	4,344 ± 11,445	−2,051
Third year	2,414 ± 7,900	4,246 ± 12,301	−1,832
Fourth year	2,676 ± 8,839	3,729 ± 11,605	−1,053
Fifth year	2,782 ± 9,187	3,618 ± 10,937	−836
Total costs of health care utilization over 5 years	12,110	19,561	−7,451
Total costs over 5 years	12,267	19,561	−7,294

Note: figures may not add up to the total as a result of rounding.

adopted the former approach for two reasons. First, it allowed us to detect any possible positive or negative impact of RAMP-DM on other public health services. Second, it was quite difficult to clearly define "diabetes-related" care. Most studies that adopted the latter approach only included the costs related to the care of selected diabetes-related complications (37–39) and acknowledged this as a limitation (34).

Although the usual-care group had slightly higher health service utilization and costs at baseline than the RAMP-DM group (1,359 vs. 1,347 USD), the difference could not account for the usual-care group's substantially higher costs than the RAMP-DM group in the subsequent years. Both groups showed an increase in the health service costs with time, which could be partly due to increased service needs with age and development of complications. The sharp increases in the costs in the first year of follow-up in both group could be due to development of new diabetes complications.

In this study, we used the cost in 2013. It would be much more accurate if we could integrate the actual costs of subsequent years. However, the HA usually releases the upregulation of the unit costs of health service utilization every 10 years. We adopted the unit costs released in 2013 by HA, which was the closest match to our analysis. In our study, the subjects were followed up to late 2015, and there may be a two-year difference in cost, and we considered that the cost may not be significantly different between the two years. Also, if we used another index like the consumer price index or gross domestic product deflator, on one hand, the adjusted cost was not officially announced by HA, and on the other hand, it would also complicate the whole picture, as cost of various components may inflate or deflate within these years. Therefore, after taking all these into considerations, we did not convert the costs to a more recent value.

There were several strengths in this study. First, the study subjects were sampled from the population-wide database, which was representative of Hong Kong public primary care patients with diabetes. The five years' follow-up of a large sample allowed sufficient numbers of study end points to determine the effectiveness of RAMP-DM on various diabetes-related complications and mortality. Second, we collected detailed empirical data on public health service utilization to estimate the direct medical costs, which were the most valid.

Several limitations should be also noted for this study. First, this was an observational study, and unobserved factors might affect the results. We could not conclude that the reductions in the incidences of complications were all due to RAMP-DM. This study could not carry out a randomized control trial owing to the service nature of the RAMP-DM intervention; thus, the results might be affected by some unobserved potential confounders. Second, the usual-care subjects had never been invited to the

Table 4—Program costs per event avoided by RAMP-DM intervention

	No. of observed events					Program costs (USD) per event avoided by RAMP-DM intervention	
End points	RAMP-DM (*N* = 8,570)	Usual care (*N* = 8,570)	No. of events avoided	ARR (%)	NNT	Base case	Range of sensitivity analysis
Any complication	1,315	2,455	1,140	13.30	8	1,304	525–1,673
CVD	1,057	2,054	997	11.63	9	1,413	591–1,882
AMI	240	529	289	3.37	30	4,888	1,969–6,273
Other IHD	387	924	537	6.27	16	2,607	1,050–3,346
Heart failure	291	693	402	4.69	21	3,422	1,378–4,391
Stroke	445	727	282	3.29	30	4,888	1,969–6,273
ESRD	391	696	305	3.56	28	4,563	1,838–5,855
STDR	48	174	126	1.47	68	11,081	4,464–14,219
All-cause death	682	1,830	1,148	13.40	7	1,141	459–1,464

AMI, acute myocardial infarction; ARR, absolute risk reduction; ESRD, end-stage renal disease; IHD, ischemic heart disease; STDR, sight-threatening diabetic retinopathy.

program or had refused to join because they were less healthy or health conscious, leading to worse outcomes and higher health service utilization. Third, the occurrences of diabetes-related complications were defined by documented records of diagnosis, which could be biased by underdiagnoses and coding errors. Fourth, we adopted the package costs to calculate the costs of health service utilization. This might underestimate the costs of RAMP-DM participants because they might have higher medication costs as a result of there being a higher percentage of patients on glucose-lowering drugs, antihypertensive drugs, and lipid-lowering drugs (16,17). According to the HA annual report, the expenditure of drugs was <10% of total expenditure, while the staff costs accounted for ~70% of total costs (40). Therefore, the higher costs of drugs among RAMP-DM participants were minimal compared with the overall health service costs.

The RAMP-DM program cost a mean of 157 USD per patient (range 66–209) over 5 years, and the RAMP-DM had lower incidences in complications (15.34% vs. 28.65%, $P < 0.001$) and mortality (7.96% vs. 21.35%, $P < 0.001$). Participants in the RAMP-DM group had a net saving of 7,294 USD per participant over 5 years' observation from the public health provider's perspective. These findings promote RAMP-DM as part of routine care for all patients with diabetes in primary care. To estimate the long-term cost-effectiveness of RAMP-DM, we would conduct further studies to model the observed effectiveness and cost data over the lifetime.

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