Systematic Review and Meta-Analysis

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The effectiveness of the problem-based learning in medical cell biology education

A systematic meta-analysis

Wei Xu, PhD, Tingjie Ye, PhD, Xiaoling Wang, PhD*

Abstract

Background: Problem-based learning (PBL) was widely adopted in medical cell biology education for Chinese student; however, there was no systematic analysis to prove PBL was much more effective than lecture-based learning (LBL). Our aim is to evaluate the effectiveness of PBL on cell biology curriculum compared with LBL.

Method: We systematically searched the publications related to PBL teaching approach in cell biology curriculum for medical education from databases until to February 2021. Pooled standard mean differences (SMDs) and risk ratios with their 95% confidence intervals were used to assess the effectiveness of PBL and the satisfaction of students to PBL compared to LBL in meta-analysis. The heterogeneity of the included studies was assessed by statistical I^2 of heterogeneity. Meta-regression and subgroup analysis were performed to analyze the source of heterogeneity. Funnel plots and Egger tests were performed to assess publication bias.

Result: After initial searching and selection, 9 studies were included for meta-analysis. All of these 9 studies were in high quality. The SMDs (95% confidence intervals) of total examination scores and comprehensive examination scores between PBL and LBL curriculum in cell biology teaching was calculated to be 0.89 (0.52, 1.26) and 0.53 (0.29, 0.78). Meanwhile, the risk ratios of the satisfaction of PBL vs LBL were calculated to be 1.18 (0.96, 1.46). However, there was a heterogeneity among the pooled SMDs of 10 studies with $I^2 = 89.7\%$, $P < .001$. The factors including the different teachers, the similar or same examination paper and over 100 student numbers among PBL and LBL groups raised the heterogeneity in the pooled SMDs. There is no publication bias in these 10 publications after Egger and Begg test.

Conclusion: The result indicated PBL was better than LBL in improvement of examination scores and comprehensive examination scores in cell biology curriculum to some extent. However, the satisfaction of students to PBL and LBL had no difference. The factors, including the different teachers, the similar or same examination papers and over 100 student numbers, affected the effectiveness of PBL and raised the heterogeneity of the pooled SMDs.

Abbreviations: CI = confidence interval, LBL = lecture-based learning, PBL = problem-based learning, RR = risk ratio, SEPN = same examination paper or not, SMD = standard mean difference, STN = same teacher or not.

Keywords: cell biology, effectiveness, lecture-based learning, meta-analysis, problem-based learning, subgroup analysis

1. Introduction

The problem-based learning (PBL) teaching approach in medical curriculum was firstly launched by Howard S. Barrows at McMaster University in Toronto of North America in 1969. The first university adopted a medical PBL curriculum in the United States was the University of New Mexico.[1] Subsequently, Europe, China, and other countries promoted PBL curriculum in medical education.[2,3] Except for the application in medical education, other majors, such as architecture, nursing, engineer, and biology, also subsequentially adopted the PBL curriculum.[4–6] PBL is a student centered and self-motivated learning model in the process as following: problems discovering, required information collection, and solution formulation.[7] PBL requires the student having the ability to solve the practical problems through self-learning from the text, not only passively accept the knowledge from the teachers compared to the lecture-based learning (LBL).[8,9] The LBL medical curriculum is didactic lectures and was firstly implemented by the American Medical College Association and American Academy of Medicine in 1894.[10] It has been applied at the core of medical education in the majority of medical colleges. However, studies revealed that

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PBL approach was a greater effective teaching approach for acquisition of basic knowledge compared with LBL.

Khoshnevisasl et al[11] found that the median score of the exam in pediatric course was higher in the PBL group compared to the LBL group. Liu et al[12] found that the effect of PBL on the achievements of clinical curriculum for Chinese medicine students was better than LBL in clinical theoretical knowledge assessment score, clinical skills assessment score, comprehensive ability score, and teaching satisfaction. Ma and Lu[13] also found that the PBL in pediatric medical education in China was more effective than the LBL in improving theoretical knowledge, skill, and case analysis scores. These studies revealed that not only overseas, but also in China, PBL is more effective than LBL in improvement of examination score, skills, and comprehensive ability.

The PBL was also adopted and widely applied in cell biology curriculum for Chinese medical education from 2006. There were a lot of studies that revealed that PBL is more effective than LBL in improvement of examination scores and comprehensive examination scores in cell biology curriculum.[14–17] However, Jia et al[18] claimed that there was no difference between PBL and LBL in improvement of examination score in cell biology curriculum. Due to the contrary conclusion from different studies, we conducted a systematic meta-analysis of eligible studies to investigate the effectiveness of PBL on the improvement of examination score compared with LBL in medical cell biology education and provided an orientation for the PBL application promotion in medical cell biology education.

2. Material and methods

Ethical approval statements were not necessary since the present study was a meta-analysis and only associated with the related literature research.

2.1. Publication searching and selection criteria

The relevant publications were systematically searched in China National Knowledge Infrastructure, Wanfang, Cochrane, Embase, SIS Web of Science, and PubMed database until February 2021. Medical subheading terms related to cell biology in combination with words related to PBL (PBL* or Problem-Based Curriculum or Learning, Problem-Based) were used to retrieve eligible studies from the above database in Chinese or in English terms.

Studies were included in the meta-analysis if they met the following criteria: PBL approach application; the course was cell biology; studies were published in Chinese or English. Studies were excluded based on the following criteria: duplicated records; letters, reviews, case reports, or conference; studies with duplicated data or a repeated analysis; study was without LBL comparison; the majors of the students were unrelated to medical majors.

2.2. Data extraction and quality assessment

Two investigators (XW and YTJ) reviewed each article independently and extracted information from all included articles. Any disagreement was discussed and a consensus was reached for all issues. The following information was collected from each study: first author's name, year of publication, same teacher or not (STN), same teaching material or not, same examination paper or not (SEPN), majors of students, total student number, student number, mean scores, and standard error of mean from PBL and LBL group.

The quality of the included studies was assessed by the Newcastle-Ottawa quality assessment scale.[19] The scale includes 8 items with 3 different dimensions: selections (4 items, 1 star for each item), comparability (1 item, 2 stars), and outcome (3 items, 1 star for each item). Item scores were added up and used to quantitatively assess study quality. A higher score indicated higher quality. Inconsistencies in the scoring by 2 independent researchers were resolved through discussion and consultations.

2.3. Statistics analysis

Standard mean differences (SMDs) with their 95% confidence intervals (CIs) were calculated in Meta software (STATA Corporation, College Station, TX) according to number of students, average score, and standard error of mean of score in PBL and LBL group. The pooled SMDs and 95% CIs were used to estimate the effectiveness of PBL in the cell biology. The pooled risk ratios (RRs) with 95% CIs were used to indicate the satisfaction of students to PBL compared to LBL. A pooled $SMD > 0$ implies that PBL teaching approach improved the scores of cell biology compared with LBL. The heterogeneity among studies was estimated using Cochran Q test ($P_{beter} < .05$, significant heterogeneity) and the I^2 statistic ($I^2 \leq 50\%$, no or moderate heterogeneity; $I^2 > 50\%$, strong heterogeneity). The random-effects model was chosen to pool the SMD (95% CIs) to avoid significant heterogeneity ($P_{beter} < .05$ and $I^2 > 50\%$). Meta-regression and subgroup analysis were performed to analyze the source of heterogeneity. A sensitivity analysis was conducted by removing 1 study at a time to assess the stability of the results. Publication bias was assessed using the funnel analysis and Begg and Egger test, with $P < .05$ to be considered significant. All statistical analysis was performed using the STATA software, version 16.0 (STATA Corporation, College Station, TX). Meta-analysis was performed in STATA 16.0 using the metan package. All P values were 2 tailed tests.

3. Results

3.1. Database searching and study selection

One thousand four hundred eighty-six articles were identified after initial database searching, 89 articles from China National Knowledge Infrastructure database, 46 articles from Wanfang database, 194 articles from PubMed, 1117 articles from Web of Science, 32 articles from Embase, and 8 articles from Cochrane. We excluded these 138 duplicated records initially. Then, we screened the remaining record by reviewing the titles and abstracts. If the records were not related to 2 key terms (PBL and cell biology), the records would be excluded. Finally, there were 1291 records excluded totally and 57 records were remaining.

To assess whether the 57 remaining records met the inclusion and exclusion criteria, we reviewed the full text of the remaining records. Among these, we found that 44 records did not provide the raw data, 2 records were related to mix PBL approach, 1 record was repeated analysis and 1 record was non-medical major related. After full text review, 9 remaining records were included for meta-analysis. A detailed screening process was illustrated as shown in Figure 1.

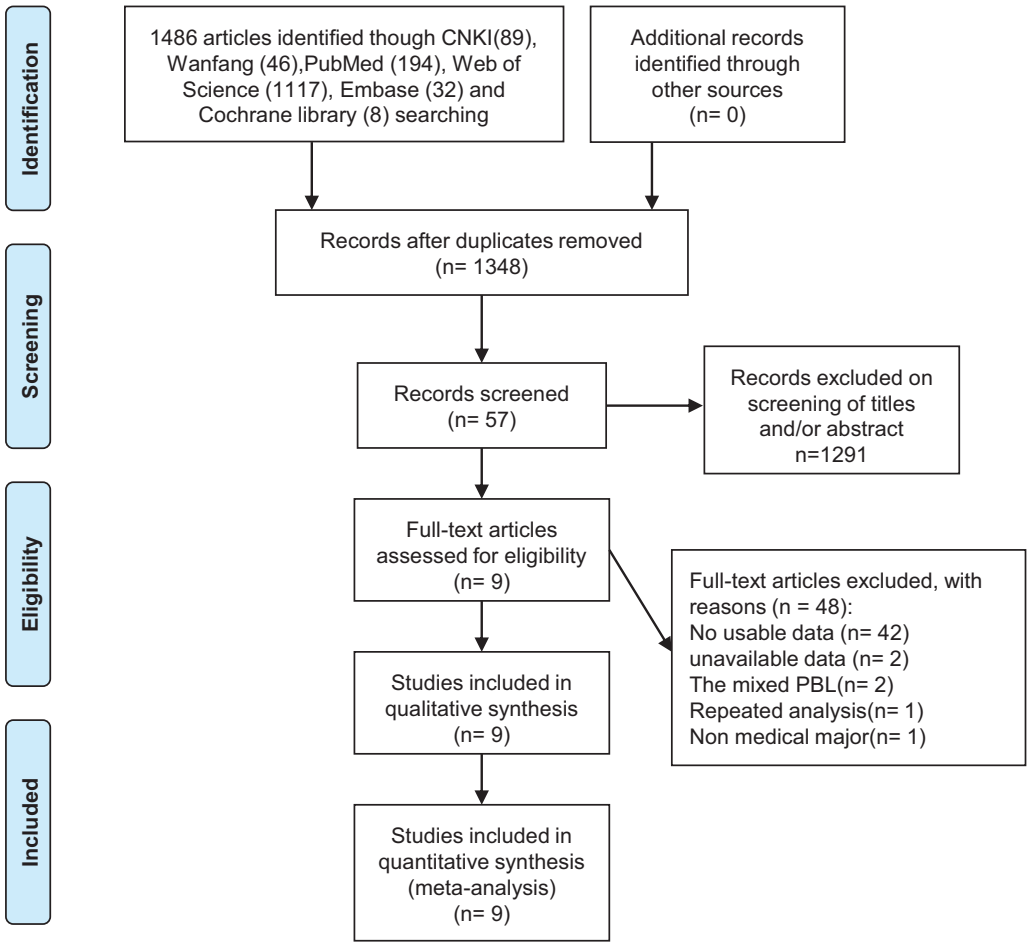

Figure 1. Methodological flow diagram for the selection of the included papers in meta-analysis. PBL = problem-based learning.

3.2. Study characteristics and quality assessment

The main characteristics of these studies were tabulated in Table 1. All the included studies were about the cell biology in Chinese medical education. The years of the publications were after 2005. There were 1269 students in the included 9 studies. The students of all studies were from Chinese clinical medical school. All of 9 studies used the same teaching materials in PBL and LBL curriculum. The teachers from 4 studies were same in PBL and LBL curriculum. From 6 studies, the similar evaluation approach was adopted in PBL and LBL curriculum. The quality of all included studies was assessed according to the Newcastle-Ottawa quality assessment scale. Among 9 studies, 8 scored 8 and 1 scored 7 as shown in Table 1. The result showed that all the included studies were of high quality.

3.3. Evaluation of effectiveness of PBL compared with LBL

The random-effects model was used to combine the effect of PBL on the improvement of mean scores in cell biology. The SMD was

Table 1

Main characteristics of the included studies.

Name	Year	STN	STMN	SEPN	Majors of students	TSN	PBL No.	PBL MS	PBL SEM	LBL No.	LBL MS	LBL SEM	NOS
Sh et al	2015	Y	Y	S	2013 clinical medicine	200	100	72.65	10.25	100	65.86	14.63	8
Li et al	2007	NA	Y	NA	2005 clinical medicine	157	51	78.24	8.36	106	69.42	7.95	7
Tang et al	2014	NA	Y	Y	2011 clinical medicine	152	76	86.58	4.71	76	80.32	4.14	8
Liu et al	2014	N	Y	S	2013 clinical medicine	221	113	69.12	14.12	108	68.89	7.30	8
Yu et al	2006	N	Y	S	2003 clinical medicine	199	106	78.24	8.36	93	69.42	7.95	8
Lan et al	2018	N	Y	S	2017 clinical medicine	101	50	88.57	4.74	51	80.32	4.14	8
Wang et al	2014	Y	Y	S	2011 medical nursing	64	32	47.65	13.36	32	39.28	18.69	8
Feng et al	2020	Y	Y	S	2018 clinical medicine	59	30	83.30	10.90	29	72.40	9.60	8
Wang et al	2012	Y	Y	Y	2010 clinical medicine	118	59	74.10	8.10	59	69.30	9.30	8

LBL = lecture-based learning, MS = mean score, NA = not available, N = not, NOS = Newcastle-Ottawa quality assessment scale, PBL = problem-based learning, S = similar, SEM = standard error of mean, SEPN = same examination paper or not, STMN = same teaching material or not, STN = same teacher or not, TSN = total students' number, Y = yes.

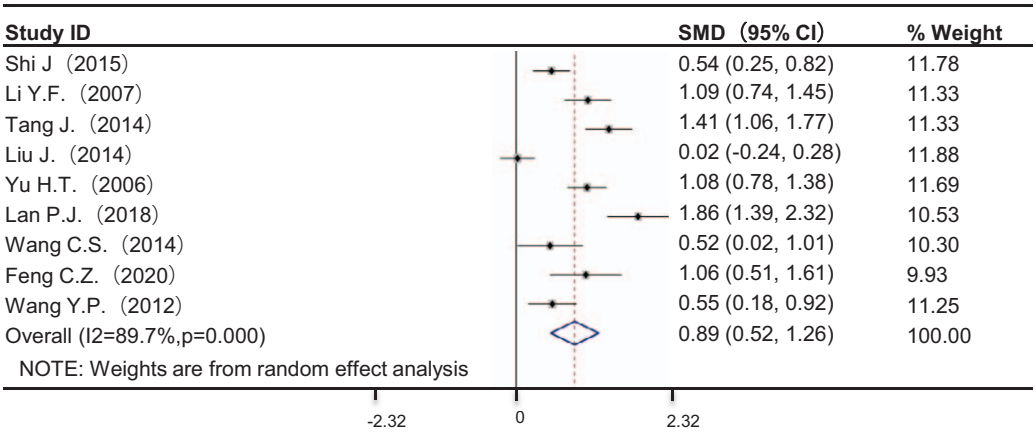

Figure 2. Forest plots for studies evaluating SMDs of examination scores of total questions from PBL vs LBL. CI = confidence interval, LBL = lecture-based learning, PBL = problem-based learning, SMD = standard mean difference.

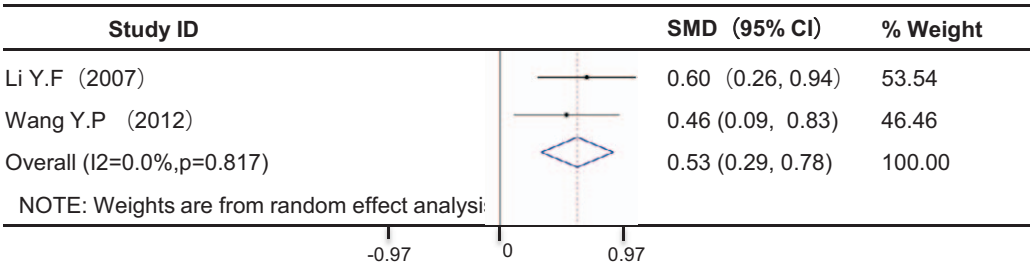

Figure 3. Forest plots for studies evaluating SMDs of examination scores of comprehensive questions from PBL vs LBL. CI = confidence interval, LBL = lecture-based learning, PBL = problem-based learning, SMD = standard mean difference.

the difference of standard mean score between PBL vs LBL curriculum and the pooled SMDs (95% CI) was calculated to be 0.89 (0.52, 1.26) (Fig. 2). This demonstrated that the PBL was better than LBL in improvement of examination scores of cell biology curriculum for medical education.

Three studies revealed the ability of student to solve comprehensive questions in PBL and LBL group. The pooled SMDs with 95% CIs of comprehensive question score were calculated to be 0.53 (0.29, 0.78) (Fig. 3). This finding proved that the ability of student from PBL curriculum to analyze and solve comprehensive questions was stronger than that from LBL curriculum.

Meanwhile, to understand the satisfaction of students to different teaching approaches, 2 of the included studies investigated the satisfaction of student. The RRs were risk rate between PBL and LBL curriculum and calculated to be 1.18 (0.96, 1.46) (Fig. 4). However, the low CI was less than 1, which indicated there was no significance for the pooled RRs. Therefore, the result indicated that there was no difference between the satisfaction of students to PBL and LBL curriculum.

3.4. Heterogeneity

The heterogeneity of pooled SMDs in these 10 studies was tested and I^2 value obtained was 89.7%, $P_{heter} < .001$, which revealed there was heterogeneity among these 9 studies (Fig. 2). Due to the heterogeneity among these 10 studies, we did regression analysis

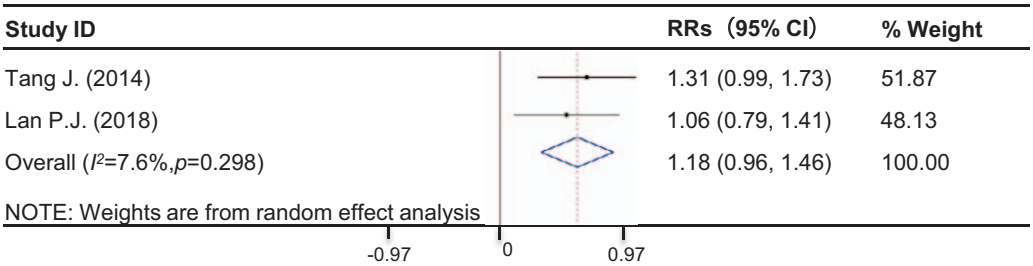

Figure 4. Forest plots for studies evaluating RRs of satisfaction rate from PBL vs LBL. CI = confidence interval, LBL = lecture-based learning, PBL = problem-based learning, RR = risk ratio.

Table 2

Statistics data of the meta-regression analysis.

SMD	Coef.	Std. Err.	t	P>|z|	95% CIs	
Year	0.011	0.634	0.17	.874	−0.191	0.213
STN	0.405	0.259	1.56	.216	−0.420	1.230
SEPN	0.227	0.481	0.47	.669	−1.303	1.756
Student No. of PBL	0.012	0.024	0.52	.638	−0.063	0.088
Student No. of LBL	−0.023	0.028	−0.85	.457	−0.112	0.065
Cons	−20.85	128.152	−0.16	.881	−428.68	386.988

CIs = confidence intervals, Coef = coefficient, Cons = constant, LBL = lecture-based learning, PBL = problem-based learning, SEPN = same examination paper or not, SMD = standard mean difference, Std. Err. = standard error, STN = same teacher or not.

to figure out the source of heterogeneity. The regression analysis was conducted based on 6 covariate factors, publication data, STN, same teaching materials or not, SEPN, PBL number, and LBL number. The result showed that *P* value of 6 factors in regression analysis was over .05, which indicated that these 6 factors did not affect the pooled SMDs and contributed to the heterogeneity of the included 9 studies (Table 2). Therefore, we aim to find out the source of heterogeneity via subgroup analysis.

We classified the 9 studies into 3 subgroups according to whether the teacher was same or not in PBL and LBL curriculum. There was a big heterogeneity among the subgroup where the teachers were different in PBL and LBL ($I^2 = 96.4\%$, $P < .001$), whereas the other 2 subgroups had no heterogeneity (Table 3). This finding indicated that the difference of teachers in PBL and LBL contributed to the heterogeneity among 9 studies. Afterward, we classified the 9 studies into 3 subgroups according to whether the same examination paper was used in PBL and LBL. The subgroup using the similar examination paper has a big heterogeneity ($I^2 = 91.4\%$, $P < .001$). Meanwhile, the same examination paper subgroup also has a big heterogeneity ($I^2 = 90.8\%$, $P = .001$). These findings revealed that the similar or same examination papers contributed to the heterogeneity among 9 studies. Finally, we divided the studies into 2 groups according to the number of the student in PBL and LBL group. When the number of students over 100, there was the heterogeneity of the subgroup ($I^2 = 92.0\%$, $P < .001$) (Table 3). This finding revealed that the number of the students over 100 also contributed to the heterogeneity among the 10 studies.

After subgroup analysis, we concluded that the factors that whether the STN, SEPN, and students' number did not affect the effectiveness of PBL on improvement of examination scores of cell biology. However, not same teacher, similar or same examination paper, and over 100 students contributed to the heterogeneity of the pooled SMDs of the included studies. Especially the studies, including Liu et al, Yu et al, Lan et al, Tang et al, and Wang et al, brought in the heterogeneity in the pooled SMDs. When these 5 studies were removed and the remaining studies were combined to pool the SMD, the pooled SMD was calculated to be 0.79 (0.46, 1.11) (Fig. 5). The result proved that these 5 studies removing did not affect the conclusion. However, there was no heterogeneity ($I^2 = 61.5\%$, $P = .05$) among the remaining 4 studies after removing. Therefore, we concluded that these 5 studies were the source of the original heterogeneity among pooled SMDs.

3.5. Sensitivity analysis

Due to the heterogeneity caused by these 5 studies, we aim to evaluate whether any single study had an influence on the stability of pooled results. Leave-one-out method was used for sensitivity analysis. We sequentially removed each study and calculated the pooled SMDs to evaluate the effect of an individual study on the pooled results. As shown in Figure 6, pooled SMDs was unstable after Liu et al study was removed, which suggested that the Liu et al study affects the stability of pooled results significantly. However, the other studies did not affect the stability of pooled result significantly.

Table 3

Statistics data of the subgroup analysis.

Variable	No. of studies	No. of patients	SMD (95% CI)	Heterogeneity			
				χ2	I^2	*P* value	Model
STN							
Same teacher	4	441	0.60 (0.41, 0.80)	0.001	3.00%	.377	Random
Unknown	2	309	1.25 (0.94, 1.57)	0.018	36.0%	.211	Random
Different teacher	3	519	0.97 (−0.03, 1.97)	0.748	96.40%	.000	Random
STMN							
Similar	6	842	0.83 (0.33, 1.33)	0.352	91.40%	.000	Random
Unknown	1	157	1.09 (0.74, 1.45)	NA	NA	NA	Random
Same	2	270	0.98 (0.14, 1.83)	0.337	90.80%	.001	Random
Student number							
>100	7	1146	0.92 (0.48, 1.36)	0.325	92.00%	.000	Random
<100	2	123	0.78 (0.24, 1.31)	0.077	52.10%	.149	Random

CI = confidence interval, SMD = standard mean difference, STMN = same teaching material or not, STN = same teacher or not.

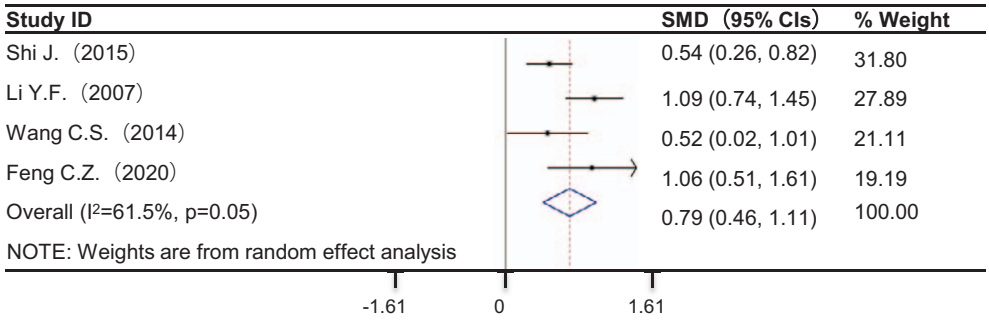

Figure 5. Forest plots for studies evaluating pooled SMDs of examination scores of total questions from PBL vs LBL after removing 5 studies. CIs = confidence intervals, LBL = lecture-based learning, PBL = problem-based learning, SMD = standard mean difference.

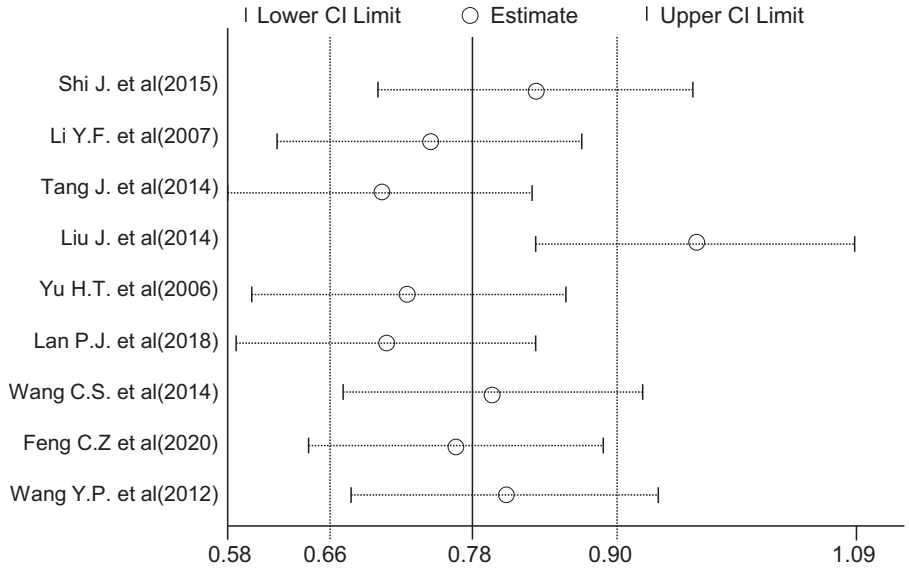

Figure 6. Effect of individual study on the pooled SMDs. CI = confidence interval.

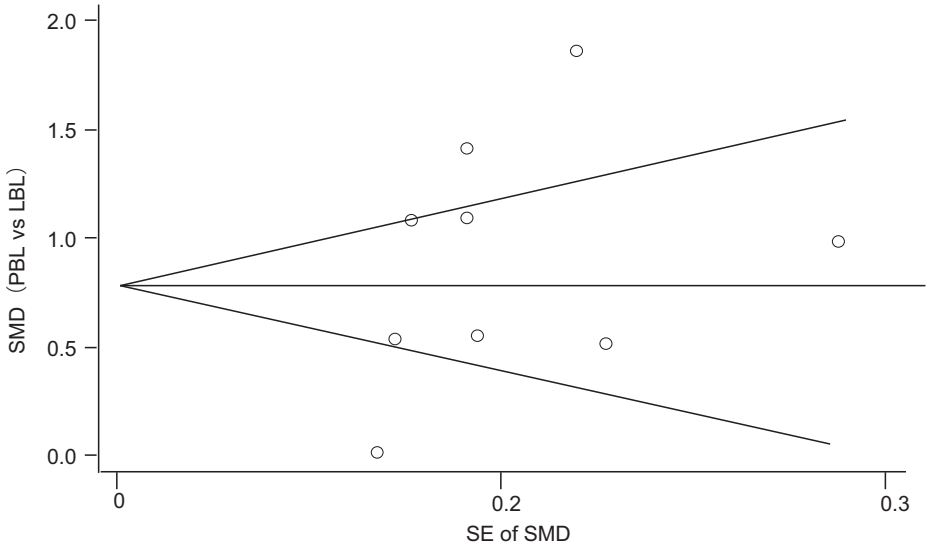

Figure 7. Begg funnel plot for publication bias assessment of all included studies. LBL = lecture-based learning, PBL = problem-based learning, SE = standard error, SMD = standard mean difference.

3.6. Publication bias

Begg funnel plot was applied to evaluate publication bias, where no asymmetry was found in the plot (Fig. 7). Meanwhile, the Begg and Egger test revealed the *P* value was over .05, which indicated that there was no evidence for a significant publication bias in the meta-analysis.

4. Discussions

The PBL teaching approach has over 5 decade's histories. At early stage, the PBL curriculum was prevalent, most of studies demonstrated that the score of the students was significantly higher in PBL compared to LBL.[20–22] Although the PBL teaching approach was adopted in cell biology for medical education presently, there was no systematic analysis to prove PBL teaching approach was more effective than LBL teaching approach. In our study, it is first time that we systemically evaluate the effectiveness of PBL compared to LBL in cell biology curriculum. To screen the unique PBL teaching approach, we excluded the mixed PBL with other teaching approach which led the number of included studies limited. In spite of that, the result still indicated that PBL teaching approach increased the score of students in cell biology curriculum significantly compared to LBL teaching approach. However, there are some issues for this study. Firstly, due to that the number of studies was not numerous; therefore, this conclusion was limited to some extent. Secondly, there was 1 study revealing a contrary conclusion which affected the pooled SMDs, which indicated that more publications about PBL in medical cell biology were required to draw a robust conclusion that the PBL was more effective than LBL in medical cell biology education.

In addition, we found there was a heterogeneity caused by 5 studies. We demonstrated that 3 factors, including different teachers, similar or same examination paper, and over 100 students, contributed to the heterogeneity in the combined effect through subgroup analysis. It indicated that the difference of the teachers, the evaluation approach, and the scale of the student number really affect the effectiveness of PBL. Importantly, the subgroup analysis showed that the similar or same examination paper caused the heterogeneity among the pooled SMDs of the included studies, which indicated that the effectiveness of PBL and LBL cannot be evaluated by the same approach or single approach. Although, the studies from Li et al and Yan et al adopted the comprehensive question to evaluate the achievements of PBL and LBL, the proportion of comprehensive question was too small in all questions to observe the huge difference of PBL and LBL in effectiveness. Taken together, it is important to explore an effective approach to significantly evaluate the PBL effect.

Although the effectiveness of PBL was better than LBL on promotion of teaching quality, the educators realized that more extensive resources was required for the operation of a PBL curriculum.[9] Therefore, over 70% of schools adopted PBL curriculum for medical education at pre-clinical year in China and USA. However, only 6% and 4.2% of school used PBL for more than 50% of pre-clinical hours in China and USA.[23,24] With the increasing strength of basic scientific research and demand of medical education reform, PBL was more prevailing. Therefore, the studies of the PBL will focus on "how PBL function" changed from "whether PBL function".[25]

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Writing – original draft: Wei Xu.
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