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Ultrasound-guided internal jugular access: systematic review and economic evaluation of cost-effectiveness

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Abstract

Introduction

Ultrasound guidance for cannulation of the internal jugular vein has been shown to improve success and complication rates in comparison with the landmark techniques.

The aim of this study is to verify if ultrasound is also cost-effective.

Materials and Methods

A systematic review of the literature in PubMed, Medline, and Google was performed between years 1966 and 2010. A decision tree model was built with failure and complication rates from the studies selected. A cost-effectiveness analysis and sensitivity analysis were performed with this model.

Randomised controlled trials on adult patients, with real-time B-mode ultrasound guidance, comparison between ultrasonography and landmark methods and reported outcomes (early complications, failures, time to successful cannulation) were included. Exclusion criteria were: enrolment of paediatric patients, ultrasound before puncture, Doppler ultrasound guidance, no clear description of outcomes, and no prospective clinical trial.

Results

About 8 randomised controlled trials were selected. The ultrasound guidance significantly reduces the occurrence of arterial puncture (risk ratio, risk ratio 0.21, 95% CI 0.13–0.33), pneumothorax complications (risk ratio 0.15, 95% CI 0.03–0.88), and cannulation failures (R 0.12, 95% CI 0.04-0.39). It proves to have € 1,225 additional cost every 1,000 procedures. The major determinants of ultrasound costs are the purchase cost of the ultrasound unit and the machine uses per week.

Conclusion

Although the ultrasound approach introduces a clinically relevant improvement of success and complication rates, it does not appear to be cost-effective.

Introduction

Central venous catheters (CVCs) are essential for the clinical management of many patients both in the acute care setting and in the chronic, long-term care.

Studies have reported an associated complication rate >15% for central venous cannulations[1,2].

Up to recent years, the internal jugular vein (IJV) has gained the greatest popularity among the different central cannulation routes due to its consistent anatomical position, large diameter, and low likelihood of catheter obstruction or misplacement[3]. This route, however, is not devoid of early mechanical complications like arterial puncture and pneumothorax.

Two meta-analyses have shown that ultrasound-guided CVC placement is associated with a significant improvement of early complication rates, length of execution, and first-pass success rate when compared with the landmark (LM) technique[4,5].

However, in a survey by the Society of Cardiovascular Anaesthesiologists only 15% of responders stated to routinely use ultrasound (US) for CVC placement[6]. A presumed higher procedural cost was among the most common objections for not utilizing this approach. According to many providers, the initial financial investments for equipment and operators' training, and fixed costs for maintenance and additional supplies (e.g. sterile sheaths), may not be outweighed by the better clinical performances of US guidance.

Calvert and coworkers have performed a decision analysis showing that B-mode US guidance for CVC placement is significantly cost-effective when compared with the traditional LM technique[7,8]. Their decision model considered a 12% incidence of arterial puncture and a 9% failure for internal jugular vein cannulations with the LM technique. Although the analysis used conservative assumptions against the US approach (such as no pneumothorax complications, expert operators, allowance of only one failed attempt), these complication rates are higher than data published in the studies on CVC placement with the LM approach[9,10].

The aim of this study is to perform a systematic review of the existing literature and to update the economic evaluation of cost-effectiveness of real-time B-mode US guidance compared with the LM technique for IJV cannulation.

Materials and Methods

Selection of studies

A search in PubMed, Medline, and Google was carried out with the following headings: central venous catheter, internal jugular vein, and ultrasound. Articles were limited to those in English. The time period was between 1966 and December 2010. Inclusion criteria were:

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studies on adult patients, real-time B-mode ultrasound guidance, comparison between ultrasonography and the LM method, and reported outcomes (early complications, failures, time to successful cannulation). Exclusion criteria were: enrolment of paediatric patients, ultrasonography before puncture, Doppler ultrasound guidance, no clear description of outcomes, no prospective clinical trial, and no randomisation. The selection flowchart is reported in Figure 1. The references quoted in any relevant article were reviewed. This research was done iteratively until no new potential citations were found. The rationale of this research strategy was to identify validation studies with the same ultrasound technique reporting outcomes which could be useful for a cost-effectiveness analysis. We did not take into account the operators' experience among inclusion criteria as a mixed group of operators was considered more representative of the average hospital setting.

Data analysis

Data were abstracted independently by the authors and compared before analysis.

The authors used piloted forms and data abstraction was focused on the rate of pneumothorax, arterial puncture, and failed cannulation attempts.

The quality of selected studies was assessed based on the risk of selection bias, attrition bias, and reporting bias.

Statistical heterogeneity (Cochran Q statistics) for complication rates was tested (significance for $p < 0.05$). Risk Ratios (RRs) for arterial puncture, pneumothorax, and cannulation failure of US guidance *vs.* LM approach were calculated using a random effects model based on an inverse variance method.

The pooled rates of arterial puncture, pneumothorax, and cannulation success with 95% confidence intervals (CIs) were used to draw a decision tree model[11] (Figure 2) and for the subsequent cost analysis.

Statistical analysis was performed using commercially available programmes (StatPlus: Mac 2009, Analysoft Inc., Alexandria, USA; RevMan 5.1, the Nordic Cochrane Center, Copenaghen, Denmark).

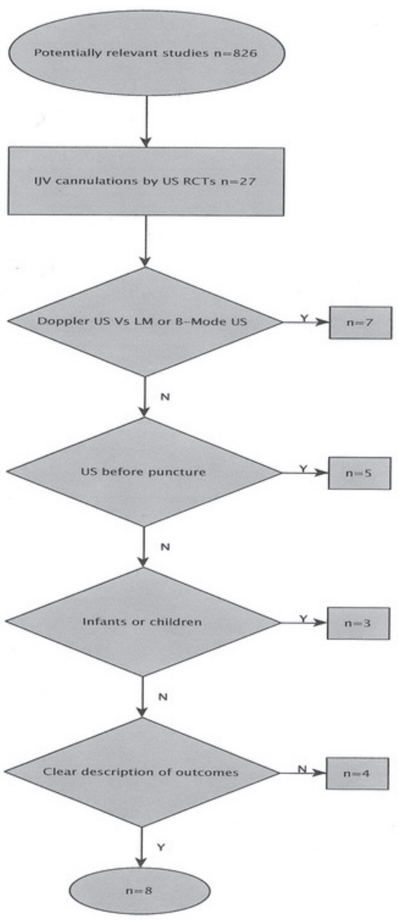

Figure 1: The selection flowchart. US, ultrasound; LM, landmark; IJV, internal jugular vein; RCTs, randomised clinical trials.

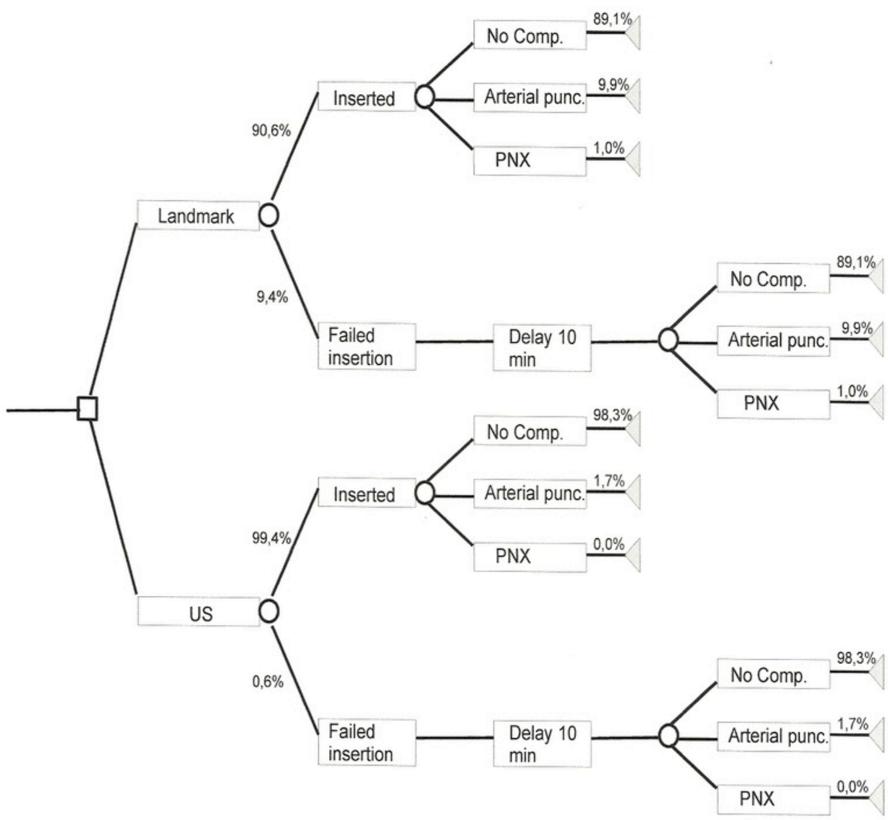

Figure 2: Decision tree with failure, arterial puncture, and pneumothorax rates. US, ultrasound; PNX, pneumothorax; punc., puncture; Comp., complications.

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Costs

The annualisation approach is based on the assumption that the money available can be spent on something else or invested for future use.

The model output includes both the cost of depreciation and the income that is forgone because funds are unavailable for alternative use[12].

These principles have been used to set the annual value of the equipment.

We assumed at 3% per annum cost of capital.

The cost of purchasing a modern portable US unit is about € 10,000 to € 20,000. As technology improves quickly, at the end of a three-year time period it is expected that the residual value of the machine and software will be zero.

Besides the purchase cost, the cost per procedure has been linked to the frequency of use of the US unit.

The cost of the training has been related to the average number of a single operator's procedures per week and to the length of the operator's remaining working life.

It was assumed that the machine cost is € 15,000 (including a maintenance contract cost of € 1,000) and that the equipment is used to insert 15 lines per week.

Use of ultrasound machine implies an estimated cost of € 1.5 for disposable cover.

The model assumes that an anaesthetist is trained by a credentialed radiologist during the first 10 hours of ultrasound procedures. To allocate costs, we also assumed that theoperator has a 20-year remaining working life and undertakes an average of two procedures per week.

Unsuccessful attempts have been quantified as a 10-minute delay for CVC placement.

The average cost of arterial puncture has been calculated at € 12 assuming a 10-minute time period spent for arterial compression. The costs of these time delays in the operating theatre have been calculated adding the staffing costs (i.e. the labour cost of a five-year experienced anaesthetist and a five-year experienced nurse) to the average hourly depreciation cost of medical equipment in the operating theatre (calculated as € 200 per hour). It was assumed that, during the procedure, no other relevant task could be performed in the same operating room. Cost of uncomplicated pneumothorax has been estimated at € 230[13,14].

Sensitivity analysis

Cost sensitivity analysis is the process of determining how variations in the configuration of key variables affect the costs of procedures. It is used to compare alternative methods. Using univariate cost sensitive analysis, we have calculated how variables need to change to obtain cost-neutral results from the use of US and LM methods.

The results of sensitivity analysis were graphically displayed in a tornado diagram. This lets one evaluate the effect associated with the uncertainty in each of the variables that affect the final cost. The interval for failure and complication rates correspond to the pooled 95% CI of the selected studies and complication and equipment costs are the base costs + 33%.

Results

Selection of studies

27 randomised clinical trials (RCTs) on the use of ultrasound for IJV cannulation were selected among 826 potentially relevant studies (Figure 1). Seven of them compared Doppler ultrasound with LM technique[15–19] or real-time B-mode US guidance[20,21], five compared ultrasonography before puncture with the LM technique or real-time US guidance[22–26], three were performed on infants or children[27–29] and four studies did not give a clear description of outcomes (no consideration of failures, arterial puncture or mention of pneumothorax)[30–33].

About eight RCTs were selected[34–41]. Details of each trial for key variables

Table 1 Details of each trial (number of cannulations, operators' experience and frequency of PNX, arterial puncture and failure for ultrasound-guided and landmark-guided technique). PNX, pneumothorax

		Ultrasound-guided			Landmark-guided			Operators' experience
	n	Arterial puncture	PNX	Failure	Arterial puncture	PNX	Failure	
Troianos 1993[34]	160	1.3%	0	0	8.4%	0	3.6%	Not reported
Denys 1993[35]	604	2.6%	0	0	8.3%	0	11.9%	Experienced (not specified)
Sulek 2000[36]	120	5%	0	5%	16.7%	0	8.3%	Experienced (not specified)
Koroglu 2006[37]	80	0	0	0	35%	2.5%	2.5%	Experienced (> 50 cannulations)
Milling 2005[38]	129	3.3%	0	0	11.6%	0	39.6%	Experienced (> 30 cannulations)
Karakitsos 2006[39]	900	1.1%	0	0	10.7%	11.4%	5.6%	Experienced (> 5 years)
Leung 2006[40]	130	1.5%	0	6.1%	6.1%	1.5%	21.5%	Postgraduate year 3 or above
Turker 2009[41]	380	0.5%	0	0.5%	4.7%	0	2.6%	Experienced (not specified)

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and operators' experience are reported in Table 1. Most of these studies showed a good approach to random sequence generation and allocation concealment mechanisms[37–41] (Table 2).

Overall 118 failures (9.4%, 95% CI 7.8%–11%) in the LM group and 8 failures (0.6%, 95% CI 0.2%–1%) in the US group were recorded (RR 0.12, 95% CI 0.04–0.39). About 125 arterial punctures (9.9%, 95% CI 8.2%–11.6%) in the LM group and 21 arterial punctures in the US group (1.7%, 95% CI 1%–2.4%) were found (RR 0.21, 95% CI 0.13–0.33). About 13 pneumothoraxes (1%, 95% CI 0%–2.7%) occurred among 1259 CVC placements with the LM technique, 0 in the US group (RR 0.15, 95% CI 0.03–0.88). Heterogeneity between studies was not significant.

Cost analysis and sensitivity

Cost and consequences of LM and US approach are reported in Table 3. The US approach avoids 82 arterial punctures and 10 pneumothoraxcomplications in a hypothetical 1000-patient sample, with € 1,225 additional cost every 1000 CVC placements.

For the US-guided approach, the cost per procedure appears to be strictly dependent on the US machine cost and its frequency of use. Table 4 reports the modelled cost per procedure according to purchase cost and cannulations per week.

The model is less sensitive to the initial investment for training, provided that the trainee has 20 years of remaining working life and performs ≥1 procedure per week (Table 5).

The results of sensitivity analysis are reported in Table 6. Figure 3 displays the impact on the costs of the uncertainty related to each key variable in the sensitivity analysis.

The modelled baseline values of failure rates, purchase cost, and number of US-guided cannulations per week are close to the threshold values needed to obtain a cost-neutral result.

Discussion

Our review of the literature confirms that the US-guided CVC placement in the IJV improves the success rate of cannulation, significantly reducing the occurrence of pneumothorax and arterial puncture[34–41]. The results of our cost analysis, however, show that the US-guided approach increases the procedural costs in the region of € 1,225 every 1000 procedures.

The ultrasound guidance for CVC placement has clearly demonstrated to improve patient care in different clinical settings and has been recommended in daily practice by several authorities[42–44].

Calvert and coworkers performed an economic evaluation[6] demonstrating that, besides being safer,

Table 2 Quality of selected study based on risk of selection, attrition, and reporting bias

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Comments
Troianos 1991[34]	Uncertain	Uncertain	Low risk	Uncertain	No mention of randomization and allocation methods, no frequency of PNX complications
Denys 1993[35]	High risk	High risk	Low risk	Uncertain	Assignment based on date of admission, no frequency of PNX complications
Sulek 2000[36]	Uncertain	Uncertain	Low risk	Uncertain	No mention of randomization and allocation methods, no frequency of PNX complications
Koroglu 2006[37]	Low risk	Uncertain	Low risk	Low risk	-
Milling 2005[38]	Low risk	Low risk	Low risk	Uncertain	Restrictive criterion for cannulation failure (5 attempts or 5 min)
Karakistos 2006[39]	Low risk	Low risk	Low risk	Low risk	-
Leung 2006[40]	Low risk	Low risk	Low risk	Uncertain	Restrictive criterion for cannulation failure (3 attempts)
Turker 2009[41]	Uncertain	Uncertain	Low risk	Low risk	No mention of randomization and allocation methods

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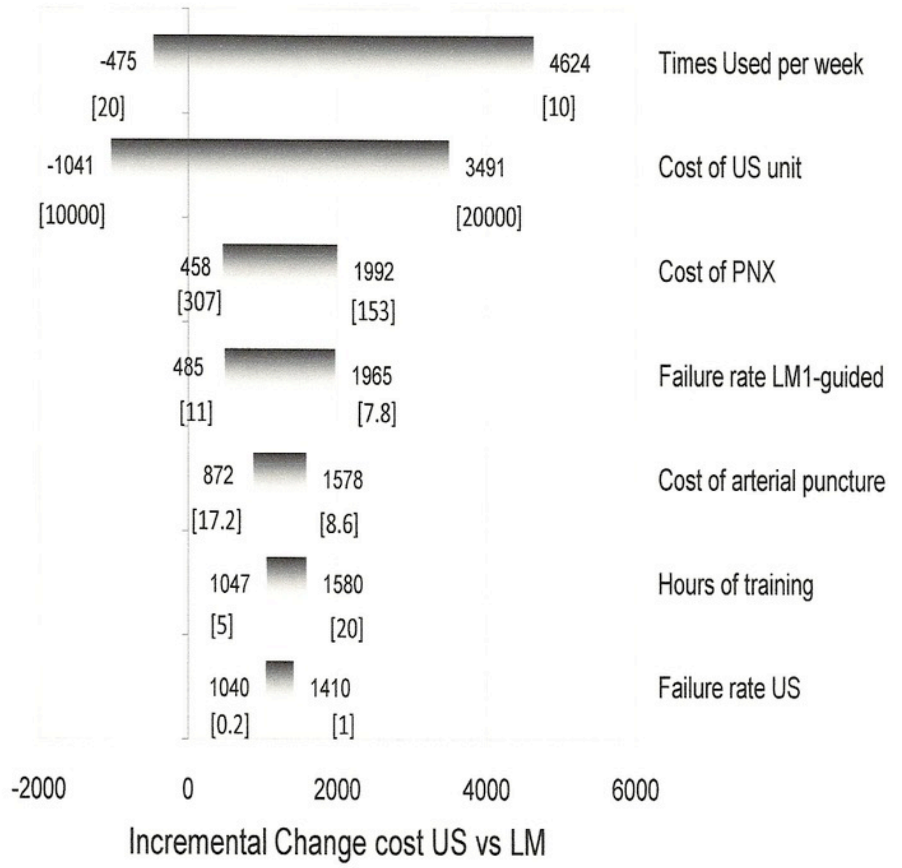

Figure 3: Tornado diagram representing a single-factor sensitivity analysis. The variables with the highest impact on final cost kept at the top of the chart followed by other variables in descending impact order.

ultrasonography is cost-effective when compared to the LM technique. Most of their assumptions, however, have been criticised[45,46], specifically those such as the use of arterial puncture as the only complication, the quality of selected trial[30,34,36], the training costs, and the complication costs[47].

We recalculated the complication rates focusing on eight RCTs with similar design characteristics[34–41]. Although the operators' experience was reported heterogeneously and the clinical setting varied greatly, these studies gave statistically homogeneous results for complication rates. Hence, we assumed that their data could be generalised and applied to our model. Moreover, since we performed a cost-effectiveness evaluation, we believe that data coming from a mixed population of operators could be more representative of the average clinical scenario than data obtained only from experienced operators.

We also reevaluated the impact of arterial puncture on the final costs. We took into account the case of an uncomplicated needle injury, which is the most recurrent arterial trauma in CVC placement. In this case, the common management approach is based on a 3 to 15 minutes compression and cost is mainly related to the time elapsed before a new cannulation attempt[49]. The occurrence of more serious arterial injuries is generally related to the insertion of large-bore catheters in the carotid artery and is an infrequent adverse event[50].

Our analysis also considered the impact of pneumothorax, which was not included in the aforementioned study[7].

Although the complication costs may vary considerably between different scenarios, the impact of complications on the final cost is far

Table 3 Costs and consequences per 1000 procedures with landmark and ultrasound approaches respectively

	Landmark	Ultrasound	Incremental change
Cost €	7,926	9,151	1,225
Arterial puncture	99	17	–82
Pneumothorax	10	0	–10

Table 4 Cost per procedure according to purchase costs of ultrasound units and ultrasound-guided cannulations per week

	Purchase cost		
Procedures per week	€ 10,000.00	€ 15,000.00	€ 20,000.00
1	€ 67.99	€ 101.98	€ 135.97
10	€ 6.80	€ 10.20	€ 13.60
20	€ 3.40	€ 5.10	€ 6.80

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Table 5 Average discounted training cost per procedure according to initial training cost, procedures per week, and the trainee's remaining working life

	Training cost			
	€ 550.00		€ 1,100.00	
US[1] procedures per week	5 years	40 years	5 years	40 years
1	€ 2.31	€ 0.46	€ 4.62	€ 0.92
10	€ 0.23	€ 0.05	€ 0.46	€ 0.09
20	€ 0.12	€ 0.02	€ 0.23	€ 0.05

[1]US: ultrasound-guided

Table 6 Sensitivity analysis. Threshold values indicate how a single variable needs to change to obtain a cost-neutral result from the use of ultrasound and landmark approaches.

	Baseline	Threshold
Failure rate LM[2]-guided	9.40%	12.05%
Failure rate US[3]-guided	0.60%	N/A
Cost of US unit	€ 15,000.00	€ 12,297.35
Cost per US procedure	€ 8.65	€ 7.43
Cost of arterial puncture	€ 12.92	€ 27.86
Cost of PNX	€ 230.00	€ 352.50
Uses of US unit per week	15	18.3

[2]LM: landmark
[3]US: ultrasound

less significant than the impact of the purchase cost of the US unit and the number of US procedures per week, which proved to be the major determinants of our cost analysis. We used a € 15,000 price, which is close to the threshold value of our sensitivity analysis and is a reliable figure for most of the US machines in use in the operating theatre or in the ICUs. Given the history of rapid changes in technology and computer software, many other intangible assets are susceptible to technological obsolescence. A three-year period is generally considered a reliable useful life for US software and machine[51].

Few evidences exist on the time needed for training. We modelled a 10-hour period of assistance of a credentialed radiologist, which is reasonable based on recommendations from several authorities[50]. With an operator's remaining working life >20 years and >1 procedure per week, the impact of training on the final costs appears to be low.

The major limitation of our study is the exclusion of the expected time advantage of ultrasound-guidance. Reviewing the literature is practically difficult to examine this aspect, as most RCTs evaluate access time as the time between the first skin puncture and the aspiration of venous blood, and no RCT actually mentions the time needed to set the US machine or to achieve the transducer's sterility. However, in a recent observational study, although the overall procedure length was shorter with the US-guided placement of long-term tunnelled CVCs (25.9 min *vs.* 28.3 min), the actual difference may not be regarded as significant in terms of cost-effectiveness[52].

Another limitation is that our study reports data from the operating theatre where capital and staffing costs are higher than in ward-based settings and the impact on final costs is mainly related to the reduction of attempts and lower duration of the procedure, which results in lessening the chance of theatre lists overrunning or having to be curtailed. Even though it is likely that the costs per procedure of LM and US-guided approach are similar in different scenarios (given the expected higher rates of complicated insertions and delays, which compensate the lower capital costs in emergency or ward-based settings), the effective consequences of resource saving are practically difficult to be shown outside the operating theatre.

Finally, it has been argued that the anatomical knowledge arising from ultrasound studies can make the LM approach considerably safer, improving success and complication rates with an unpredictable impact on cost-effectiveness in future practice[53].

Conclusion

Although the US-guided CVC placement of the IJV provides a clinically relevant improvement of success and complication rates and a significant reduction of failed attempts, it does not appear to be cost-effective when compared with LM technique in the operating theatre. The major determinant of the final cost per procedure is the initial investment, specifically, the purchase cost of the ultrasound unit. The training cost does not have a significant impact on the costs.

Abbreviations list

CIs, confidence intervals; CVCs, central venous catheters; IJV, internal jugular vein; LM, landmark; RCTs, randomised controlled trials; RR, risk ratio; US, ultrasound.

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