ONLINE FIRST | HEALTH CARE REFORM

Preventing Pressure Ulcers in Long-term Care

A Cost-effectiveness Analysis

Ba' Pham, MSc, PhD(C); Anita Stern, PhD; Wendong Chen, PhD; Beate Sander, PhD; Ava John-Baptiste, PhD; Hla-Hla Thein, PhD; Tara Gomes, MHSc; Walter P. Wodchis, PhD; Ahmed Bayoumi, MD; Márcio Machado, PhD; Steven Carcone, MSc; Murray Krahn, MD

Background: Pressure ulcers are common in many care settings, with adverse health outcomes and high treatment costs. We evaluated the cost-effectiveness of evidence-based strategies to improve current prevention practice in long-term care facilities.

Methods: We used a validated Markov model to compare current prevention practice with the following 4 quality improvement strategies: (1) pressure redistribution mattresses for all residents, (2) oral nutritional supplements for high-risk residents with recent weight loss, (3) skin emollients for high-risk residents with dry skin, and (4) foam cleansing for high-risk residents requiring incontinence care. Primary outcomes included lifetime risk of stage 2 to 4 pressure ulcers, quality-adjusted life-years (QALYs), and lifetime costs, calculated according to a single health care payer's perspective and expressed in 2009 Canadian dollars (Can$1 = US$0.84).

Results: Strategies cost on average $11.66 per resident per week. They reduced lifetime risk; the associated number needed to treat was 45 (strategy 1), 63 (strategy 4), 158 (strategy 3), and 333 (strategy 2). Strategy 1 and 4 minimally improved QALYs and reduced the mean lifetime cost by $115 and $179 per resident, respectively. The cost per QALY gained was approximately $78 000 for strategy 3 and $7.8 million for strategy 2. If decision makers are willing to pay up to $50 000 for 1 QALY gained, the probability that improving prevention is cost-effective is 94% (strategy 4), 82% (strategy 1), 43% (strategy 3), and 1% (strategy 2).

Conclusions: The clinical and economic evidence supports pressure redistribution mattresses for all long-term care residents. Improving prevention with perineal foam cleansers and dry skin emollients appears to be cost-effective, but firm conclusions are limited by the available clinical evidence.

Arch Intern Med. 2011;171(20):1839-1847.
Published online September 26, 2011.
doi:10.1001/archinternmed.2011.473

PRESSURE ULCERS ARE LOCALized injury to the skin and underlying tissue, usually over bony prominences.[1] They are mostly a preventable complication of medical care[2] but remain common in many care settings.[3] In particular, long-term care residents are at high risk of developing pressure ulcers because of immobility,[4] poor nutritional status,[5] impaired mental status,[6] and incontinence.[4,6] Pressure ulcers are associated with adverse effects on health,[7] social well-being,[8] quality of life,[9] and high treatment costs—approximately US$3.3 billion per year in 2008.[10]

See also pages 1831 and 1854

Preventing the development of pressure ulcers is an important aspect of improving long-term care quality.[11] However, the cost implications of different quality improvement strategies are not well described.[12] In 2008, the Ontario Health Technology Advisory Committee, a panel that makes recommendations to the Ontario Ministry of Health and Long-Term Care regarding the uptake and diffusion of health technologies,[13] commissioned an evidence synthesis and a cost-effectiveness analysis of pressure ulcer prevention.[14,15] Based on our previous work and recent systematic reviews of pressure ulcer prevention,[12,14,16-18] the present study evaluates the cost-effectiveness of evidence-based strategies to improve current prevention practice in long-term care facilities.

Author Affiliations are listed at the end of this article.

METHODS

OVERVIEW AND STUDY POPULATION

We conducted the cost-effectiveness analysis according to guidelines by the Canadian Agency for Drugs and Technologies in Health[19] and the

Table 1. Intervention Effect and Quality of Supporting Randomized Controlled Trials (RCTs)

Strategy	Description of Preventive Interventions	Participant Population	No. of RCTs/ No. of Participants	Pressure Ulcers, RR (95% CI)[b]	Randomization[a]	Allocation Concealment[a]	Blinding of Outcome Assessment[a]	Source
1	Pressure redistribution foam (ie, cubed foams,[24,25] visco-elastic foam,[26] and high-density foams)[25-27] vs standard hospital mattresses	Medical, surgical, and rehabilitation patients	5/2016	0.40 (0.21-0.74)	4 RCTs	2 RCTs	None	McInnes et al[16]
2	Oral nutritional supplements (eg, daily drinks of 237 mL, 2 kcal/mL)[28] and standard hospital diet vs standard hospital diet	Elderly hospital patients	4/1224	0.85 (0.73-0.99)	4 RCTs	None	1 RCT	Stratton et al[17]
3	A hyperoxygenated fatty acid regimen for skin dryness, applied twice per day to the sacrum, trochanter, and heels (Mepentol; Laboratorios Bama-Geve SA, Barcelona, Spain) vs matched greasy placebo[22]	Patients from home care and/or geriatric centers	1/380	0.42 (0.22-0.80)	1 RCT	None	1 RCT	Reddy et al[12]
4	A foam cleanser combining an emollient, a water-repellent barrier, and a water-repellent deodorant (Clinisan; Shiloh Health Care, Oldham, England) vs soap and water for incontinence care[23]	Residents of long-term care sites	1/93	0.32 (0.13-0.82)	1 RCT	None	1 RCT	Hodgkinson et al[18]

Abbreviations: RR, relative risk of pressure ulcers; SR, systematic review.

[a] Number of RCT(s) reporting items pertaining to the risk of bias in RCTs, abstracted from systematic reviews: random sequence generation, adequately concealed treatment allocation, and adequate blinding of outcome assessment.[29]

[b] Uncertainty in the relative risk estimates were characterized using log-normal distributions for the probabilistic sensitivity analysis.

Panel on Cost Effectiveness in Health and Medicine.[20] Health outcomes included lifetime risk of pressure ulcers and quality-adjusted life-years (QALYs). All costs, expressed in 2009 Canadian dollars (Can$1 = US$0.84),[21] were calculated from the perspective of a single health care payer. Future health outcomes and costs were discounted at 3%.

Our base case analysis considered long-term care residents, with a mean age of 83 years, a life expectancy of 3.8 years, and a 3-month risk of a stage 2 to 4 pressure ulcer of 2.6% (eTable 1; http://www.archinternmed.com).

QUALITY IMPROVEMENT STRATEGIES

We considered the following evidence-informed strategies to improve current prevention practice.

- Strategy 1: Replace all standard mattresses in long-term care facilities with pressure redistribution mattresses (supporting evidence from 5 randomized controlled trials [RCTs]).[16]
- Strategy 2: Provide daily oral nutritional supplements to high-risk residents with recent weight loss (4 RCTs).[17]
- Strategy 3: Apply a skin emollient daily to dry skin of high-risk residents (1 RCT, 380 participants).[12,22]
- Strategy 4: Replace soap and water with a foam cleanser for high-risk residents requiring bladder and/or bowel incontinence care (1 RCT, 132 participants).[18,23]

Table 1 describes the preventive interventions in details. Because the strategies address different impairments, they are not mutually exclusive. We therefore compared each strategy with current practice. We did not consider strategies that combined these interventions because their synergistic effect is uncertain.[12] In practice, however, these interventions are key elements of a comprehensive skin care program.[30-32]

EFFECTIVENESS EVIDENCE SUPPORTING THE PREVENTIVE INTERVENTIONS

The methodological quality of the supporting evidence is generally suboptimal (Table 1), according to current systematic reviews.[12,14,16-18] The multiple RCTs supporting strategies 1 and 2 were mostly conducted with inadequate blinding of outcome assessment. Nevertheless, the results appear to be clear-cut with low risk of error in accepting the significant prevention effect.[33] Strategy 3 or 4 is supported by a small RCT reporting a significantly large prevention effect.[22,23] There could be a moderate to high risk of error in accepting the reported effect.[33,34]

DECISION MODEL

We used a validated Markov model with a 1-week cycle to simulate pressure ulcer–related health events whose likelihoods depend on the prevention effectiveness.[15] Every week, a simulated resident is at risk of developing a pressure ulcer. According to the original staging system from the National Pressure Ulcer Advisory Panel, simulated pressure ulcers are classified as stage 1 (persistent redness of skin), stage 2 (loss of partial thickness of skin, appearing as an abrasion, blister, or shallow crater), stage 3 (loss of full thickness of skin, presented as a deep crater), and stage 4 (loss of full thickness of skin, exposing muscle or bone).[35] We originally considered deep-tissue injury[15] but excluded it because of its low prevalence in nursing homes (eg, 0.1%).[36]

The eFigure displays the stage-specific Markov states, with additional stratification by the following prognostic indicators for wound healing: age groups (ie, 80-84 years, 85-89 years, ≥90 years), risk status (ie, low or high risk),[37] wound status (chronic or healable, defined as progressing toward skin closure within 6 months for stage 2-4),[38] local infection (stage 2-4 only),[39] systemic infection (stage 3-4 only),[40] and care setting (long-term care

Table 2. Pressure Ulcer Risk and Prognosis, Current Prevention Practice, Health-Related Quality of Life, and Costs

Variable	Base Case	Standard Error or Range	Distribution[a]	Reference No. or Source
Pressure ulcer risk and prognosis				
Risk-adjustment scale[b]				Berlowitz et al[43,44]
High risk of developing pressure ulcers, %	63.2	4.4	Beta	RAI-MDS
Risk factors among high risk residents, %				
Recent weight loss[c]	26.2	4.0	Beta	RAI-MDS
Dry skin[d]	22.7	3.8	Beta	RAI-MDS
Bladder or bowel incontinence[e]	72.1	4.1	Beta	RAI-MDS
Transition rates among high-risk residents, %				
Weekly incidence of stage 1 pressure ulcers	0.68	0.42 to 0.83	Age specific	RAI-MDS
Weekly transition rate from stage 1 to 2	3.36	2.20 to 4.05	Age specific	RAI-MDS
Weekly transition rate from stage 2 to 3	0.12	0.05 to 0.33	Age specific	RAI-MDS
Weekly transition rate from stage 3 to 4	0.71	0.19 to 1.18	Age specific	RAI-MDS
Weekly healing rate for stage 1	18.14	9.18 to 23.59	Age specific	RAI-MDS
Weekly healing rate for stage 2	1.34	0.37 to 1.54	Age specific	RAI-MDS
Weekly healing rate for stage 3	0.73	0.14 to 1.11	Age specific	RAI-MDS
Weekly healing rate for stage 4	0.23	0.09 to 0.58	Age specific	RAI-MDS
Incidence of pressure ulcer related infection, %				
Weekly local infection rate given stage 2-4	1.21	0.47	Beta	RAI-MDS
Weekly sepsis rate given local infection in stage 3-4	1.28	0.43	Beta	RAI-MDS
Current prevention practice in long-term care facilities				
Use of standard mattresses, %	54.5	31.0 to 77.0	Beta	Practice survey
Use of pressure redistribution mattresses, %	45.5	23.0 to 69.0	Beta	Practice survey
Use of soap and water for incontinence care, %	50.0	0 to 100	Beta	Practice survey
Hospitalization and mortality				
Weekly hospitalization rate among high-risk residents, %[f]	1.46	0.14	Age specific	CIHI-DAD
Mean length of hospital stay, d	6.8	Not varied		CIHI-DAD
Inpatient mortality among high-risk hospitalized residents, %[f]	16.63	4.94	Age specific	CIHI-DAD
Annual long-term care mortality among high-risk residents, %[f]	13.78	2.32	Age specific	RAI-MDS
Excess mortality due to pressure ulcer(s), %[g]	7.23	0.23	Beta	Zhan and Miller[45]
Quality of life weights, score (range, 0-1)				RAI-MDS
Mean quality of life weight among residents with intact skin	0.36	0.17	Gamma	Wodchis et al[46]
Mean decrement weight with stage 2-4 pressure ulcers	0.022	0.004	Gamma	Thein et al[9]
Cost inputs				
Long-term care cost, $				
Weekly cost for nursing and personal care	557.20	Not varied		OMHLTC
Other weekly costs, eg, food, programming, accommodations	430.22	Not varied		OMHLTC
Case-mix index				CIHI[47]
An average complex continuing care resident	1.00	Reference level		CIHI[47]
Low-risk: pressure ulcer stage 0-1	0.52	0.13	Log-normal	RAI-MDS
Low-risk: pressure ulcer stage 2	0.54	0.13	Log-normal	RAI-MDS
Low-risk: pressure ulcer stage 3-4	0.70	0.13	Log-normal	RAI-MDS
High-risk: pressure ulcer stage 0-1	0.71	0.11	Log-normal	RAI-MDS
High-risk: pressure ulcer stage 2	0.90	0.11	Log-normal	RAI-MDS
High-risk: pressure ulcer stage 3-4	0.94	0.06	Log-normal	RAI-MDS

(*continued*)

facilities or hospitals).[41] Residents with systemic infection were assumed to be hospitalized, and in rare instances, could die from the infection.[42] At any time, simulated residents could be hospitalized or die because of other causes. The model was constructed in TreeAge Pro 2009 Suite (TreeAge Software, Williamstown, Massachusetts).

MODEL INPUTS

Table 2 displays key inputs derived from a population-based cohort, a telephone survey of current prevention practice, linked administrative databases (eAppendix), and literature reviews.

Population-Based Cohort

We included all residents from 89 long-term care facilities in Ontario, Canada (overall, 613 facilities), that participated in the first implementation phase of the Resident Assessment Instrument–Minimum Data Set (RAI-MDS, version 2.0) from May 2004 to November 2007. The RAI-MDS is mandated for minimum data collection to inform care monitoring and planning.[54] Included residents must have had a full RAI-MDS assessment (eg, physical functioning, cognition, nutritional status, skin health, and incontinence) and at least 1 reassessment (eg, every 3 months or when health status changed).[55] The cohort consisted of 18 325 residents (overall, approximately 92 000 residents). The 3-month incidence of stage 2 to 4 pressure ulcers in our cohort was 2.6%, similar to that reported in US long-term care facilities (eTable 1).[43,44]

Telephone Survey of Current Prevention Practice in Ontario Long-term Care Facilities

We surveyed the directors of care from a random sample of 34 facilities (26 facilities responded) regarding their facility size; staffing ratios and salaries; types, numbers, and costs of mattresses; repositioning programs; nutritional supplements; and incontinence care (Table 2).[15] Still common in the surveyed facilities are standard mattresses (55% of long-term care beds) and incontinence care with soap and water (eg, 50% of care episodes).

Table 2. Pressure Ulcer Risk and Prognosis, Current Prevention Practice, Health-Related Quality of Life, and Costs (continued)

Variable	Base Case	Standard Error or Range	Distribution[a]	Reference No. or Source
Cost inputs				
Incremental costs of preventive interventions				
Pressure redistribution foam mattresses, $				McInnes et al[16]
Weekly cost per resident, $	1.26	0.35 to 2.45	Gamma	Derived
Unit price of standard mattresses, $	225	Not varied		Practice survey
Unit price of pressure redistribution foam mattresses, $	450	350 to 500		Practice survey
Mean lifespan of all mattresses, y	3.5	3.5 to 7.0		Practice survey
Oral nutritional supplements				Stratton et al[17]
Weekly cost per resident (supply and staff time), $[h]	39.55	27.65 to 41.51	Gamma	Derived
Weekly supply cost, $	9.87	7.84 to 11.83		Practice survey
Weekly staff time cost, $	29.68	19.81 to 29.68		Practice survey
Unit price of a 237-mL package of 2 kcal/mL, $	1.41	1.12 to 1.69		Practice survey
Hyperoxygenated fatty acid skin moisturizer (Mepentol; Laboratorios Bama-Geve SA, Barcelona, Spain)				Torra i Bou et al[22]
Weekly cost per resident (supply and staff time), $[i]	6.51	3.50 to 7.98	Gamma	Derived
Weekly supply cost, $	2.52	2.03 to 3.64		Torra i Bou et al[22]
Weekly staff time cost, $	3.99	1.47 to 4.34		Bliss et al[48]
Unit price of a Mepentol package, $	9.33	7.46 to 13.58		Torra i Bou et al[22]
Foam cleanser for incontinence care (Clinisan; Shiloh Health Care, Oldham, England)				Cooper and Gray[23]
Weekly cost per resident (supply and staff time), $[j]	−0.70	−38.64 to 14.07	Gamma[k]	Derived
Weekly supply cost, $	2.80	1.26 to 15.54		Cooper et al[49]
Weekly staff time cost, $	−3.50	−1.47 to −39.9		Bliss et al[48]
Unit price of a 400-mL canister of Clinisan, $	3.22	2.58 to 3.86		Cooper et al[49]
Mean time saving per incontinence care episode, min[l]	0.35	0.15 to 9.67		Bliss et al[48]; Whittingham and May[50]; Byers et al[51]; Lewis- Byers and Thayer[52]; Bale et al[53]

Abbreviations: CIHI-DAD, Canadian Institute of Health Information–Discharge Abstract Database; OMHLTC, Ontario Ministry of Health and Long-Term Care; Practice Survey, survey of current prevention practice; RAI-MDS, Resident Assessment Instrument–Minimum Data Set.

[a] Distributions to characterize the input variation and uncertainty for probabilistic sensitivity analysis.

[b] The risk assessment scale was based on 17 RAI-MDS items.

[c] RAI-MDS item K3a=1.

[d] RAI-MDS items M1=0 and M5=h.

[e] RAI-MDS item H1ab=2,3,4.

[f] Events were not related to pressure ulcers.

[g] This excess mortality estimate was used in sensitivity analysis only.

[h] Cost was based on a mean of 7.5 minute of a personal support worker's time (mean hourly rate of $16.97) to prepare and administer an oral supplemental meal (eg, half of a 237-mL package), twice daily.

[i] Cost was based on a mean duration of 1 minute of a personal support worker's time per moisturizing application, twice daily, and approximately 1.2 Mepentol packages per month.

[j] Cost was based on a mean time saving per change, a mean 5 changes per day, at an hourly rate of a personal support worker, and approximately 40 changes per 400-mL canister of Clinisan.

[k] The gamma distribution was assumed after exponential transformation of the cost values.

[l] Mean time saving per incontinence care episode by replacing soap and water with the foam cleanser.

Simulated Residents at High Risk for Pressure Ulcer Development

We identified high-risk residents using a validated risk-adjustment scale developed by Berlowitz et al[43,44] (2001) (Table 2). The scale uses 17 RAI-MDS variables (including a stage 1 pressure ulcer) to predict the risk of stage 2 or higher pressure ulcers. High-risk residents (63%) were defined as those who had a 3-month predicted pressure ulcer incidence of greater than 1%.

Pressure Ulcer Prognosis

Few studies report comprehensive data on pressure ulcer prognosis.[56] We therefore estimated stage-specific transition rates in the eFigure using RAI-MDS data from successive skin assessments (eAppendix and eTable 2).[15] Among high-risk residents, the estimated incidence of developing a stage 1 pressure ulcer was 0.68% per week (Table 2).

Quality of Life Weights

We used the Minimum Data Set–Health Status Index,[46,57] a validated algorithm for predicting Health Utilities Index scores from selected RAI-MDS items (Table 2).[58] The mean health utility score was 0.36 (range, 0-1) and was low because 44% of the residents were bedfast and 65% were incontinent (eTable 1). Residents with stage 2 to 4 pressure ulcers had lower mean scores. After we adjusted for comorbidities, the associated mean (SE) decrement was 0.022 (0.004).[9] We combined utility and longevity to calculate QALYs.[59]

Costs

Long-term care costs cover nursing and personal care, food, basic accommodation, and other costs (Table 2).[60] The base cost for nursing and personal care was adjusted using the RAI-MDS case-mix index to reflect individual care.[47] The mean weekly cost attributable to additional care was $106 for stage 2 and $128 for stage 3 or 4 pressure ulcers. For strategy 1, the mean weekly cost was $1.26 per resident, derived by amortizing the cost of upgrading to pressure redistribution foam mattresses over their lifespan (Table 2). The weekly cost was $39.55 for strategy 2 and $6.51 for strategy 3, including both supply and staff time costs. For strategy 4, the weekly supply cost was $2.80, but incontinence care could be faster with foam cleansing than with soap and water, resulting in a mean staff time

Table 3. Results of the Base Case Analysis According to the Quality of the Evidence[a]

Strategy	Incremental Cost, $ (Current Practice: Mean Cost,[b] $148 939)	Incremental QALD (Current Practice: Mean QALY,[b] 1.2421)	Incremental Cost per QALY	Lifetime Risk, % (95% CI)[c]	NNT[d]
Prevention strategy supported by high quality of evidence					
Strategy 1: Pressure redistribution mattresses for all residents	(115)	0.31	Dominant[e]	6.1 (3.2-6.7)	45
Strategy 2: Oral nutritional supplements for high-risk residents with recent weight loss	731	0.03	7 824 747	8.0 (4.4-9.3)	333
Prevention strategy supported by low quality of evidence					
Strategy 3: A skin emollient for high-risk residents with dry skin	24	0.11	78 286	7.7 (3.9-8.3)	158
Strategy 4: A foam cleanser for high-risk residents requiring incontinence care	(179)	0.20	Dominant[e]	6.7 (3.3-7.7)	63

Abbreviations: NNT, number needed to treat to prevent 1 stage 2 to 4 pressure ulcer over a resident's lifetime; QALD, quality-adjusted life-days; QALY, quality-adjusted life-years.

[a] Costs are expressed in 2009 Canadian dollars (Can$1 = US$0.84). Values in parentheses indicate cost saving.

[b] Discounted at 3%.

[c] Lifetime risk of stage 2-4 pressure ulcers; projections and ranges were derived from the probabilistic sensitivity analysis. The lifetime risk of current practice was 8.3 (95% CI, 4.7-9.5).

[d] Each NNT is the reciprocal of the lifetime risk reduction between a prevention strategy and current practice.[61]

[e] Dominant: the strategy is more effective, with higher mean QALYs, and less costly than current practice.

saving of $3.50 per week, although the variation in staff time cost was large.

BASE CASE AND SENSITIVITY ANALYSES

We projected the absolute reduction in lifetime risk of stage 2 to 4 pressure ulcers between each quality-improvement strategy and current practice. We derived the corresponding number needed to treat by taking the reciprocal of the absolute risk reduction.[61] We calculated the incremental cost and incremental QALY of each strategy, and if applicable, derived the incremental cost per QALY gained.[59]

Our base case analysis considered the risk of death due to systemic infections that are related to pressure ulcers. In a large study of medical injuries during hospitalization, Zhan and Miller[45] estimate that pressure ulcers are associated with approximately 7% excess risk of all-cause mortality (Table 2). We conducted a series of sensitivity analyses: (1) with the excess mortality risk estimate, (2) from a long-term care perspective, and (3) for strategies 2 to 4, with supply costs only. For the latter, staff time required to conduct preventive interventions that are recommended by practice guidelines was considered part of current practice.[31,32,62] To account for the joint input uncertainty, we conducted a probabilistic sensitivity analysis by sampling 10 000 random values from the input distributions specified in Table 1 and Table 2 and eTable 2.[63]

RESULTS

BASE CASE ANALYSIS

Table 3 summarizes results of the base case analysis, stratified by quality of the clinical evidence. Strategies 1 and 2 are supported by relatively high-quality evidence, whereas strategies 3 and 4 are supported by low-quality evidence. The projected lifetime risk of pressure ulcers was 8.3% with current practice, and ranged from 6.1% to 8.0% with quality improvement strategies. Over a lifetime, the number needed to treat to prevent 1 pressure ulcer was 45 for strategy 1, 63 for strategy 4, 158 for strategy 3, and 333 for strategy 2.

In Table 3, the expected health gain was mainly due to reduced morbidity rather than mortality and was very small: 0.31quality-adjusted life-days gained (discounted) for strategy 1, 0.20 for strategy 2, 0.11 for strategy 3, and 0.05 for strategy 4. With current practice, the mean lifetime cost (including accommodation, food, and support services for activities of daily living) was approximately $149 000 per resident (discounted). Strategies 1 and 4 minimally improved QALYs and reduced the mean lifetime cost by $115 and $179, respectively. Strategy 2 increased the mean lifetime cost by $731 (0.5% of $149 000), corresponding to an incremental cost per QALY gained of approximately $7.8 million. The corresponding figures for strategy 3 was $24 and approximately $78 000, respectively.

SENSITIVITY ANALYSIS

Table 4 displays the sensitivity analysis results. Taking the excess mortality risk attributable to pressure ulcers into account, improved prevention increased life expectancy as well as mean lifetime costs. For example, strategy 1 increased life expectancy by 1.61 quality-adjusted life-days (discounted, or 4.59 life-days, undiscounted) and increased the mean lifetime cost by $389, corresponding to a cost per QALY gained of approximately $88 000. From the long-term care perspective, strategies 1 and 4 still reduced lifetime costs. According to the results from Table 4, excluding staff time cost improved the cost-effectiveness of strategy 2, turned strategy 3 into a cost-saving option, and decreased the mean cost saving of strategy 4.

The **Figure** displays results of the probabilistic sensitivity analysis, in the form of cost-effectiveness acceptability curves. Each curve shows the probability that each quality improvement strategy is more cost-effective than current practice for different willingness-to-pay values. If decision makers are willing to pay up to $50 000 (or $100 000) per additional QALY, the probability that qual-

Table 4. Results of Sensitivity Analyses

Strategy	Incremental Cost, $	Incremental QALD	Cost per QALY Gained
Strategy 1: Pressure redistribution mattresses for all residents (base case)	–115	0.31	NA
With excess all-cause mortality attributable to pressure ulcers[a]	389	1.61	88 423
Long-term care perspective	–35	0.31	NA
Strategy 2: Oral nutrition supplements for high-risk residents with recent weight loss	731	0.03	7 824 747
With excess all-cause mortality attributable to pressure ulcers[a]	786	0.18	1 599 767
Long-term care perspective	739	0.03	7 913 025
Supply cost only[b]	162	0.03	1 738 528
Strategy 3: A skin emollient for high-risk residents with dry skin	24	0.11	78 286
With excess all-cause mortality attributable to pressure ulcers[a]	209	0.58	130 915
Long-term care perspective	51	0.11	166 560
Supply cost only[b]	–44	0.11	NA
Strategy 4: A foam cleanser for high-risk residents requiring incontinence care	–179	0.20	NA
With excess all-cause mortality attributable to pressure ulcers[a]	163	1.08	55 223
Long-term care perspective	–130	0.20	NA
Supply cost only[b]	–85	0.20	NA

Abbreviations: QALD, quality-adjusted life-days; QALY, quality-adjusted life-years; NA, not applicable.
[a] An excess mortality of 7.23% was attributable to the presence of pressure ulcers.[45]
[b] The base case analysis included both supply and staff time cost. This analysis excluded staff time costs because care activities related to these strategies could be considered part of current practice, according to practice guidelines.[32,62,64]

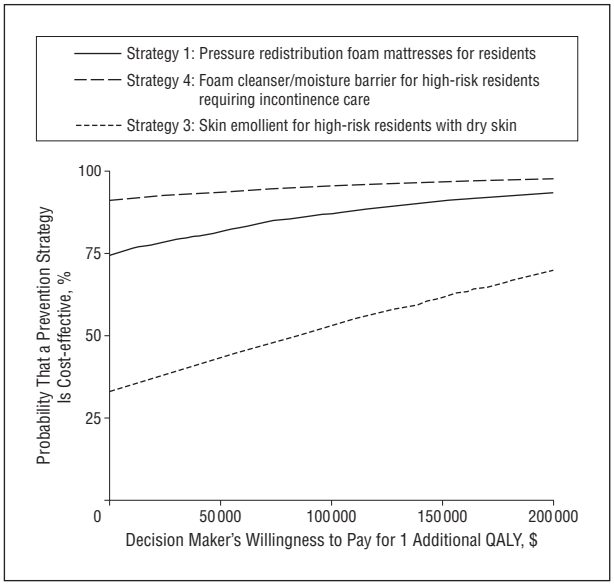

Figure. Probability that a prevention strategy is more cost-effective than current practice. The probability that strategy 2 with oral nutritional supplements is more cost-effective than current prevention practice ranged from 1% to 7% and was not plotted in the Figure. QALY indicates quality-adjusted life-year.

ity improvement is cost-effective is 94% (96%) for strategy 4, 82% (87%) for strategy 1, 43% (53%) for strategy 3, and 1% (8%) for strategy 2.

COMMENT

PRESSURE REDISTRIBUTION MATTRESSES

According to current systematic reviews, pressure redistribution foam mattresses (including cubed foams,[24,25] visco-elastic foam,[26] and high-density foams),[25-27] significantly reduce pressure ulcer incidence.[12,14,16] We showed the associated quality improvement strategy is likely to improve health and save costs. Other cost-effectiveness analyses report qualitatively similar results; the overall cost increase due to improving prevention was minimal compared with the cost avoidance associated with the reduction or delay of pressure ulcers.[65-67]

ORAL NUTRITIONAL SUPPLEMENTS

By improving tissue tolerance to pressure and oxygen shortage,[68] nutritional supports are an important measure to reduce pressure ulcer risk.[69] According to current systematic reviews,[12,14,17] oral nutritional supplements (eg, daily drinks of 237 mL, 2 kcal/mL) are associated with a significant but relatively small prevention effect.[28] We showed that the associated strategy is not cost-effective, but there may be wider health benefits (eg, supporting other strategies, reversing unintentional weight loss, and reducing infections) that we could not fully capture in our analysis.[70]

SKIN EMOLLIENT

Dry sacral skin seems to be a significant and independent risk factor for pressure ulcer development.[5] Compared with a matched greasy placebo, a hyperoxygenated fatty acid regimen for dry skin was reported to significantly reduce pressure ulcer incidence.[22] This trial result, however, could be at risk of a false-positive error because of a lack of an intent-to-treat analysis.[34] Citing results from this trial, a recent international guideline recommended skin emollients to hydrate dry skin to reduce risk of skin damage.[32] Given the available clinical evidence, we showed that the associated strategy may be cost-effective. But firmer conclusion is not possible without additional clinical data.

FOAM CLEANSER

No-rinse cleansing is the recommended approach for incontinence care.[62,64] According to our results, the use of soap and water, however, is still common. With increasing frequency, washing with soap and water has a significant disrupting effect on the skin's barrier function.[71] Instead of soap and water, incontinence care with a foam cleanser (in combination with an emollient, a water-repellent barrier and a water-repellent deodorant) was reported to significantly reduce pressure ulcer incidence.[18,23] The finding of this small trial, however, could be influenced by publication bias, the phenomenon that small studies with significant results are likely to be published.[72] Given the existing clinical evidence, we showed that the associated strategy could improve health, save staff time, and reduce costs. Additional clinical data, however, are needed to confirm our finding.

LIMITATIONS

Although the focus of our study is on improving prevention in long-term care residents, many of the supporting trials were conducted with acute care patients.[24-28] A few trials were conducted as long as 17 years ago[24,25]; generalizability to current practice may be limited by the fact that the types of available devices may have changed. Because of the low prevalence of deep-tissue injuries in long-term care,[36] we did not explicitly consider their consequences in our analysis. Also, we did not evaluate any repositioning strategies because the evidence in this area is evolving. Repositioning will be the focus of a separate analysis.

POLICY IMPLICATIONS

Partially based on data reported herein, the Ontario Health Technology Assessment Committee recommended pressure-redistribution foam mattresses for all long-term care facilities in Ontario and the evaluation of repositioning schedules on the new support surfaces.[73] Subsequently, the Ontario Ministry of Health and Long-Term Care contributed funding to an on-going trial evaluating repositioning schedules that had been funded originally by the National Institutes of Health.

CONCLUSIONS

The clinical and economic evidence supports pressure redistribution mattresses for all long-term care residents. Improved prevention with perineal foam cleansers and dry skin emollients appears to be cost-effective, but firm conclusions are limited by the available clinical evidence.

Accepted for Publication: August 7, 2011.
Published Online: September 26, 2011. doi:10.1001/archinternmed.2011.473
Author Affiliations: Toronto Health Economics & Technology Assessment Collaborative (Drs Pham, Stern, Chen, Sander, John-Baptiste, Thein, Wodchis, Bayoumi, Machado, and Krahn and Mr Carcone), Health Policy Management and Evaluation (Drs Pham, Sander, John-Baptiste, Wodchis, Bayoumi, and Krahn), Dalla Lana School of Public Health (Dr Thein), and Leslie Dan Faculty of Pharmacy (Dr Krahn), University of Toronto, Toronto, Ontario, Canada; University Health Network, Toronto (Drs John-Baptiste and Krahn); Ontario Ministry of Health and Long-Term Care, Toronto (Ms Gomes); Institute for Clinical Evaluative Sciences, Toronto (Dr Wodchis); Toronto Rehabilitation Institute, Toronto (Dr Wodchis); and Li Ka Shing Knowledge Institute, St Michael's Hospital, Toronto (Dr Bayoumi). Ms Gomes is now with the Institute for Clinical Evaluative Sciences and the Leslie Dan Faculty of Pharmacy, University of Toronto, Toronto. Dr Machado is now with GlaxoSmithKline, Rio de Janeiro, Brazil.
Correspondence: Ba' Pham, MSc, PhD(C), Toronto Health Economics and Technology Assessment Collaborative, Department of Health Policy Management and Evaluation, University of Toronto, Leslie Dan Pharmacy Bldg, 144 College St, Sixth Floor, Room 651, Toronto, ON M5S 3M2, Canada (ba.pham@theta.utoronto.ca).
Author Contributions: Dr Pham had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design:* Pham, Chen, Sander, John-Baptiste, Thein, Wodchis, and Krahn. *Acquisition of data:* Pham, Stern, Thein, Gomes, Carcone, and Krahn. *Analysis and interpretation of data:* Pham, Chen, Sander, John-Baptiste, Thein, Gomes, Wodchis, Bayoumi, Machado, and Krahn. *Drafting of the manuscript:* Pham, Chen, Machado, and Krahn. *Critical revision of the manuscript for important intellectual content:* Pham, Stern, Sander, John-Baptiste, Thein, Gomes, Wodchis, Bayoumi, Carcone, and Krahn. *Statistical analysis:* Pham, Chen, John-Baptiste, Wodchis, Bayoumi, and Machado. *Obtained funding:* Pham and Krahn. *Administrative, technical, and material support:* Thein, Machado, Carcone, and Krahn. *Study supervision:* Krahn. *Economic analysis of cost data:* Sander. *Validation of the model:* John-Baptiste.
Financial Disclosure: None reported.
Funding/Support: Funding for this study was provided in part by the Ontario Ministry of Health and Long-Term Care to the Toronto Health Economics and Technology Assessment (THETA) Collaborative. The THETA Collaborative provides technology assessment support for the Ontario Health Technology Advisory Committee and the Medical Advisory Secretariat at Health Quality Ontario, an independent agency.
Role of the Sponsors: The funder had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; and preparation, review, or approval of the manuscript.
Previous Presentations: This study was presented as a poster at the 2009 Symposium, Canadian Agency for Drugs and Technologies in Health; April 5-9, 2009; Ottawa, Ontario, Canada; and as an oral presentation at the 31st Annual Meeting of the Society for Medical Decision Making; October 19, 2009; Los Angeles, California.
Additional Contributions: Nancy Parslow, RN, ET, of the Toronto General Hospital, provided insightful comments and help during the preparation of the manuscript.

Online-Only Material: The eAppendix, eTables 1 and 2, and eFigure are available at http://www.archinternmed.com.

REFERENCES

1. National Pressure Ulcer Advisory Panel, European Pressure Ulcer Advisory Panel. *Prevention and Treatment of Pressure Ulcers: Clinical Practice Guideline*. Washington, DC: National Pressure Ulcer Advisory Panel; 2009.
2. Milstein A. Ending extra payment for "never events"—stronger incentives for patients' safety. *N Engl J Med*. 2009;360(23):2388-2390.
3. Pressure ulcers in America: prevalence, incidence, and implications for the future: an executive summary of the National Pressure Ulcer Advisory Panel monograph. *Adv Skin Wound Care*. 2001;14(4):208-215.
4. Baumgarten M, Margolis DJ, Localio AR, et al. Pressure ulcers among elderly patients early in the hospital stay. *J Gerontol A Biol Sci Med Sci*. 2006;61(7):749-754.
5. Allman RM, Goode PS, Patrick MM, Burst N, Bartolucci AA. Pressure ulcer risk factors among hospitalized patients with activity limitation. *JAMA*. 1995;273(11):865-870.
6. Maklebust J, Magnan MA. Risk factors associated with having a pressure ulcer: a secondary data analysis. *Adv Wound Care*. 1994;7(6):25-28, 27-28, 31-34 passim.
7. Franks PJ, Winterberg H, Moffatt CJ. Health-related quality of life and pressure ulceration assessment in patients treated in the community. *Wound Repair Regen*. 2002;10(3):133-140.
8. Langemo DK, Melland H, Hanson D, Olson B, Hunter S. The lived experience of having a pressure ulcer: a qualitative analysis. *Adv Skin Wound Care*. 2000;13(5):225-235.
9. Thein HH, Gomes T, Krahn MD, Wodchis WP. Health status utilities and the impact of pressure ulcers in long-term care residents in Ontario. *Qual Life Res*. 2010;19(1):81-89.
10. Van Den Bos J, Rustagi K, Gray T, Halford M, Ziemkiewicz E, Shreve J. The $17.1 billion problem: the annual cost of measurable medical errors. *Health Aff (Millwood)*. 2011;30(4):596-603.
11. Lyder CH. Implications of pressure ulcers and its relation to federal tag 314. *Ann Long Term Care*. 2006;14(4):19-24.
12. Reddy M, Gill SS, Rochon PA. Preventing pressure ulcers: a systematic review. *JAMA*. 2006;296(8):974-984.
13. Levin L, Goeree R, Sikich N, et al. Establishing a comprehensive continuum from an evidentiary base to policy development for health technologies: the Ontario experience. *Int J Technol Assess Health Care*. 2007;23(3):299-309.
14. Medical Advisory Secretariat. Pressure ulcer prevention: an evidence-based analysis. Toronto, Ontario: Ontario Ministry of Health and Long-Term Care; Technology Assessment Series, 2009;9(2). http://www.health.gov.on.ca/english/providers/program/mas/tech/reviews/pdf/rev_pup_20090401.pdf. Accessed January 4, 2011.
15. Toronto Health Economics and Technology Assessment (THETA) Collaborative. Cost Effectiveness of Prevention Strategies for Pressure Ulcers in Long-Term Care: Projection from the Ontario Pressure Ulcer Model. 2008. THETA Report No. 001. http://theta.utoronto.ca/papers/THETA_PU_Prevention_LTC_Final_Report.pdf. Accessed December 4, 2010.
16. McInnes E, Bell-Syer SEM, Dumville JC, Legood R, Cullum NA. Support surfaces for pressure ulcer prevention. *Cochrane Database Syst Rev*. 2008;(4):CD001735.
17. Stratton RJ, Ek AC, Engfer M, et al. Enteral nutritional support in prevention and treatment of pressure ulcers: a systematic review and meta-analysis. *Ageing Res Rev*. 2005;4(3):422-450.
18. Hodgkinson B, Nay R, Wilson J. A systematic review of topical skin care in aged care facilities. *J Clin Nurs*. 2007;16(1):129-136.
19. Canadian Agency for Drugs and Technologies in Health. Guidelines for the economic evaluation of health technologies: Canada. 3rd ed. Ottawa, Ontario: Canadian Agency for Drugs and Technologies in Health. 2006. http://www.cadth.ca/media/pdf/186_EconomicGuidelines_e.pdf. Accessed January 12, 2008.
20. Weinstein MC, Siegel JE, Gold MR, Kamlet MS, Russell LB. Recommendations of the Panel on Cost-effectiveness in Health and Medicine. *JAMA*. 1996;276(15):1253-1258.
21. Organization for Economic Co-Operation and Development. Prices and Purchasing Power Parities (PPP). 2010. http://www.oecd.org/department/0,3355,en_2649_34347_1_1_1_1_1,00.html. Accessed April 11, 2010.
22. Torra i Bou JE, Segovia Gómez T, Verdú Soriano J, Nolasco Bonmatí A, Rueda López J, Arboix i Perejamo M. The effectiveness of a hyperoxygenated fatty acid compound in preventing pressure ulcers. *J Wound Care*. 2005;14(3):117-121.
23. Cooper P, Gray D. Comparison of two skin care regimes for incontinence. *Br J Nurs*. 2001;10(6)(suppl):S6-S20, S8, S10 passim.
24. Hofman A, Geelkerken RH, Wille J, Hamming JJ, Hermans J, Breslau PJ. Pressure sores and pressure-decreasing mattresses: controlled clinical trial. *Lancet*. 1994;343(8897):568-571.
25. Santy JE, Butler MK, Whyman JD. A comparison study of 6 types of hospital mattresses to determine which most effectively reduces the incidence of pressure sores in elderly patients with hip fractures in a District General Hospital. Report to Northern & Yorkshire Regional Health Authority, Newcastle upon Tyne, England; 1994.
26. Russell LJ, Reynolds TM, Park C, et al; PPUS-1 Study Group. Randomized clinical trial comparing 2 support surfaces: results of the Prevention of Pressure Ulcers Study. *Adv Skin Wound Care*. 2003;16(6):317-327.
27. Gray DG, Campbell M. A randomized clinical trial of two types of foam mattresses. *J Tissue Viability*. 1994;4(4):128-132.
28. Bourdel-Marchasson I, Barateau M, Rondeau V, et al; GAGE Group. A multicenter trial of the effects of oral nutritional supplementation in critically ill older inpatients. *Nutrition*. 2000;16(1):1-5.
29. Higgins J, Green S, eds. *Cochrane Handbook for Systematic Reviews of Interventions: Version 5.0.0 (updated September 2009)*. London, England: The Cochrane Collaboration; 2009.
30. Institute of Healthcare Improvement. Protecting 5 million lives from harm: getting started kit: prevent pressure ulcers. http://www.ihi.org/knowledge/Pages/Tools/HowtoGuidePreventPressureUlcers.aspx. 2006. Accessed December 12, 2009.
31. Registered Nurses Association of Ontario. Assessment & Management of Stage I to IV Pressure Ulcers—Revised 2007. http://www.rnao.org/Page.asp?PageID=828&ContentID=721. Accessed May 28, 2008.
32. European Pressure Ulcer Advisory Panel and National Pressure Ulcer Advisory Panel. *Prevention and Treatment of Pressure Ulcers: Quick Reference Guide*. Washington, DC: National Pressure Ulcer Advisory Panel; 2009.
33. Sackett DL. Rules of evidence and clinical recommendations on the use of antithrombotic agents. *Chest*. 1989;95(2)(suppl):2S-4S.
34. Nelson AL. The effectiveness of a hyperoxygenated fatty acid compound in preventing pressure ulcers—extended commentary on a trial. *Eur Wound Manage Assoc J*. 2005;5(2):34-41.
35. National Pressure Ulcer Advisory Panel. Pressure ulcer stages revised by NPUAP. 2007. http://www.npuap.org/pr2.htm. Accessed November 8, 2008.
36. Kottner J, Dassen T, Lahmann N. Prevalence of deep tissue injuries in hospitals and nursing homes: two cross-sectional studies. *Int J Nurs Stud*. 2010;47(6):665-670.
37. Bergstrom N, Braden BJ, Laguzza A, Holman V. The Braden scale for predicting pressure sore risk. *Nurs Res*. 1987;36(4):205-210.
38. Kane D. Chronic wound healing and chronic wound management. In: Krasner DL, Rodeheaver GT, Sibbald RG, eds. *Chronic Wound Care: A Clinical Source Book for Healthcare Professionals*. 4th ed. Malvern, PA: HMP Communications; 2007:11-24.
39. Healy B, Freedman A. Infections. *BMJ*. 2006;332(7545):838-841.
40. Bansal C, Scott R, Stewart D, Cockerell CJ. Decubitus ulcers: a review of the literature. *Int J Dermatol*. 2005;44(10):805-810.
41. Woodbury MG, Houghton PE. Prevalence of pressure ulcers in Canadian healthcare settings. *Ostomy Wound Manage*. 2004;50(10):22-24, 26, 28, 30, 32, 34, 36-38.
42. Tourangeau AE, Tu JV. Developing risk-adjusted 30-day hospital mortality rates. *Res Nurs Health*. 2003;26(6):483-496.
43. Berlowitz DR, Brandeis GH, Anderson JJ, et al. Evaluation of a risk-adjustment model for pressure ulcer development using the Minimum Data Set. *J Am Geriatr Soc*. 2001;49(7):872-876.
44. Berlowitz DR, Brandeis GH, Morris JN, et al. Deriving a risk-adjustment model for pressure ulcer development using the Minimum Data Set. *J Am Geriatr Soc*. 2001;49(7):866-871.
45. Zhan C, Miller MR. Excess length of stay, charges, and mortality attributable to medical injuries during hospitalization. *JAMA*. 2003;290(14):1868-1874.
46. Wodchis WP, Hirdes JP, Feeny DH. Health-related quality of life measure based on the minimum data set. *Int J Technol Assess Health Care*. 2003;19(3):490-506.
47. Canadian Institute of Health Information. Case mix. 2010. http://www.cihi.ca/CIHI-ext-portal/internet/EN/TabbedContent/standards+and+data+submission/standards/case+mix/cihi010690. Accessed December 12, 2010.
48. Bliss DZ, Zehrer C, Savik K, Smith G, Hedblom E. An economic evaluation of four skin damage prevention regimens in nursing home residents with incontinence: economics of skin damage prevention. *J Wound Ostomy Continence Nurs*. 2007;34(2):143-152.
49. Cooper P, Gray D, Russell F. Comparing Tena Wash Mousse with Clinisan Foam Cleanser: the results of a comparative study. *Wounds UK*. 2008;4(3):12-21.
50. Whittingham K, May S. Cleansing regimens for continence care. *Prof Nurse*. 1998;14(3):167-172.
51. Byers PH, Ryan PA, Regan MB, Shields A, Carta SG. Effects of incontinence care cleansing regimens on skin integrity. *J Wound Ostomy Continence Nurs*. 1995;22(4):187-192.
52. Lewis-Byers K, Thayer D. An evaluation of two incontinence skin care protocols in a long-term care setting. *Ostomy Wound Manage*. 2002;48(12):44-51.

53. Bale S, Tebble N, Jones V, Price P. The benefits of implementing a new skin care protocol in nursing homes. *J Tissue Viability*. 2004;14(2):44-50.
54. Hutchinson AM, Milke DL, Maisey S, et al. The Resident Assessment Instrument-Minimum Data Set 2.0 quality indicators: a systematic review. *BMC Health Serv Res*. 2010;10:166-179.
55. Canadian Institute of Health Information, InterRAI Corporation. Minimum Data Set (MDS) 2.0, Canadian version 2002. http://www.cihi.ca/CIHI-ext-portal/internet/en/document/types+of+care/hospital+care/continuing+care/services_ccrs. Accessed January 7, 2010.
56. Schoonhoven L, Defloor T, Grypdonck MH. Incidence of pressure ulcers due to surgery. *J Clin Nurs*. 2002;11(4):479-487.
57. Wodchis WP, Maxwell CJ, Venturini A, et al. Study of observed and self-reported HRQL in older frail adults found group-level congruence and individual-level differences. *J Clin Epidemiol*. 2007;60(5):502-511.
58. Torrance GW, Furlong W, Feeny D, Boyle M. Multi-attribute preference functions. Health Utilities Index. *Pharmacoeconomics*. 1995;7(6):503-520.
59. Drummond M. Introducing economic and quality of life measurements into clinical studies. *Ann Med*. 2001;33(5):344-349.
60. Cameron JM. Case-mix and resource use in long-term care. *Med Care*. 1985;23(4):296-309.
61. Laupacis A, Sackett DL, Roberts RS. An assessment of clinically useful measures of the consequences of treatment. *N Engl J Med*. 1988;318(26):1728-1733.
62. Panel on the Prediction and Prevention of Pressure Ulcers in Adults. *Pressure Ulcers in Adults: Prediction and Prevention: Clinical Practice Guideline No. 3*. Rockville, MD: Agency for Health Care Policy and Research; 1992. AHCPR Publication No. 92-0047.
63. Briggs AH, Claxton K, Sculpher MJ. *Further Developments in Decision Analytic Models for Economic Evaluation*. New York, NY: Oxford University Press; 2006:122-165.
64. Registered Nurses Association of Ontario. Risk assessment and prevention of pressure ulcers. 2007; http://www.rnao.org/Page.asp?PageID=828&ContentID=721. Accessed May 28, 2008.
65. Iglesias C, Nixon J, Cranny G, et al; PRESSURE Trial Group. Pressure relieving support surfaces (PRESSURE) trial: cost effectiveness analysis. *BMJ*. 2006;332(7555):1416.
66. Inman KJ, Sibbald WJ, Rutledge FS, Clark BJ. Clinical utility and cost-effectiveness of an air suspension bed in the prevention of pressure ulcers. *JAMA*. 1993;269(9):1139-1143.
67. Padula WV, Mishra MK, Makic MB, Sullivan PW. Improving the quality of pressure ulcer care with prevention: a cost-effectiveness analysis. *Med Care*. 2011;49(4):385-392.
68. Defloor T. The risk of pressure sores: a conceptual scheme. *J Clin Nurs*. 1999;8(2):206-216.
69. Feuchtinger J, Halfens RJ, Dassen T. Pressure ulcer risk factors in cardiac surgery: a review of the research literature. *Heart Lung*. 2005;34(6):375-385.
70. Milne AC, Potter J, Vivanti A, Avenell A. Protein and energy supplementation in elderly people at risk from malnutrition. *Cochrane Database Syst Rev*. 2009;(2):CD003288. doi:10.1002/14651858.CD003288.pub3.
71. Voegell D. Care or harm: exploring essential components in skin care regimens. *Br J Nurs*. 2008;17(1):24-30.
72. Egger M, Smith GD. Bias in location and selection of studies. *BMJ*. 1998;316(7124):61-66.
73. Ontario Health Technology Advisory Committee (OHTAC). OHTAC Recommendation: Prevention and treatment of pressure ulcers. 2009: http://www.health.gov.on.ca/english/providers/program/mas/tech/ohtas/tech_pup_20090507.html. Accessed November 2, 2009.