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# Alternating pressure air mattresses as prevention for pressure ulcers: A literature review

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**Abstract**

*Objectives:* The purpose of this paper is to examine and synthesise the literature on alternating pressure air mattresses (APAMs) as a preventive measure for pressure ulcers.
*Design:* Literature review.
*Data sources:* PubMed, Cinahl, Central, Embase, and Medline databases were searched to identify original and relevant articles. Additional publications were retrieved from the references cited in the publications identified during the electronic database search.
*Results:* Thirty-five studies were included. Effectiveness and comfort of APAMs were the main focuses of the studies evaluating APAMs. Pressure ulcer incidence, contact interface pressure, and blood perfusion were the most frequently used outcome measures to evaluate the effectiveness of APAMs. Fifteen randomised controlled trials (RCTs) analysed the pressure ulcer incidence. One RCT compared a standard hospital mattress with an APAM and found that the APAM was a more effective preventive measure. RCTs comparing APAMs with constant-low-air mattresses resulted in conflicting evidence. There was also no clear evidence as to which type of APAM performed better. All RCTs had methodological flaws. The use of contact interface pressure and blood perfusion measurements to evaluate the effectiveness of APAMs is questionable. Comfort of APAMs was the primary outcome measure in only four studies. Different methods for assessment were used and different types of APAMs were evaluated. Better measures for comfort are needed. A few studies discussed technical problems associated with APAMs. Educating nurses in the correct use of APAMs is advisable.
*Conclusion:* Taking into account the methodological issues, we can conclude that APAMs are likely to be more effective than standard hospital mattresses. Contact interface pressure and blood perfusion give only a hypothetical conclusion about APAMs' effectiveness. Additional large, high-quality RCTs are needed. No conclusions can be drawn regarding the comfort of APAMs. A number of technical problems associated with APAMs are related to nurses' improper use of the devices.


*Keywords:* Alternating pressure air mattresses; Literature review; Pressure ulcer; Prevention

**What is already known about the topic?**

- Alternating pressure air mattresses (APAMs) are an effective preventive measure because they reduce the

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duration of pressure and shearing forces by alternating inflation and deflation of air-filled cells.
- The relative benefits of APAMs and constant-low-pressure mattresses and of different types of APAMs for the prevention of pressure ulcers are unclear.

**What this paper adds**

- Taking into account the methodological issues of the randomised controlled trials (RCTs), APAMs are likely to be more effective than standard hospital mattresses.
- Contact interface pressure measurements and blood perfusion measurements are not suited for evaluating APAMs. The contact interface pressure and blood perfusion change continuously. It is not clear which value(s) should be used.
- Additional sufficiently large RCTs of good design are necessary to provide evidence about the effectiveness of APAMs.
- Patient's comfort on an APAM is important, but better measures and more studies are needed to evaluate the comfort of an APAM.
- Technical problems can occur in APAMs and are due in part to incorrect use by the nurses.

## 1. Introduction

Pressure ulcers are a frequently occurring complication in patients with reduced mobility and poor health. They are caused by unrelieved pressure and shearing forces (Defloor, 1999). These two forces can interrupt the blood circulation to underlying tissues. This results in oxygen depletion in soft tissues and muscles (Panel for the Prediction and Prevention of Pressure Ulcers in Adults, 1992). The prevalence of pressure ulcers in European hospitals has been estimated at 18.1% (Clark et al., 2002). The American National Pressure Ulcer Advisory Panel (NPUAP) reported prevalence rates ranging from 10% to 18% in general acute care (NPUAP, 2001). Effective preventive measures reduce the intensity and/or the duration of pressure and shearing forces and consequently guarantee a sufficient oxygen supply to tissues (Defloor, 2000). The duration can be reduced by alternating the area under pressure. This can be achieved by repositioning or by using alternating pressure air mattresses (APAMs) (McLeod, 1997). APAMs generate alternating high and low interface pressures between body and support surface by alternating the inflation and deflation of air-filled cells (Cullum et al., 2006). The periodical pressure relief generated by the APAM enables the restoration of the blood supply to tissues (Jakobsen and Christensen, 1987; Williams, 1995).

The purpose of this paper is to examine and synthesise the literature published on the use of APAMs in the prevention of pressure ulcers. A Cochrane review regarding the effectiveness of support surfaces for pressure ulcer prevention has already been published (Cullum et al., 2006). This review, updated to May 2004, concluded that the relative benefits of APAMs and constant-low-pressure mattresses, and of different types of APAMs for pressure ulcer prevention are unclear. However, this review included only randomised controlled trials (RCTs) with pressure ulcer incidence as the primary outcome measure. The present review aims at providing a broad overview of all original studies evaluating APAMs published up to September 2006, but is not limited to only RCTs and studies with pressure ulcer incidence as the primary outcome measure.

We defined APAMs as alternating pressure air replacements (APARs) and alternating pressure air overlays (APAOs).

## 2. Method

To identify original articles on APAMs as a preventive measure for pressure ulcers; The PubMed, Cinahl, Central, Embase, and Medline databases were searched from January 1980 to September 2006. Keywords for pressure ulcers were combined with varying descriptions of APAMs and with different terms for prevention. Additional articles were located using the references cited in each of the articles retrieved by the electronic database search.

Original studies were included in the review if they investigated APAMs as a pressure ulcer preventing measure. All studies comparing an APAM with other mattresses or with other types of APAMs were included without exclusion of any study design. Articles published in English, German, French, and Dutch were included. Titles and abstracts were screened independently by two authors based on the inclusion and exclusion criteria. If there were any doubts or disagreements or if there was no abstract available, the full paper was retrieved.

## 3. Results

The PubMed search resulted in 83 articles of which 31 complied with the inclusion criteria (Tables 1 and 2). Two additional publications were identified in Cinahl and one in Central. No additional articles were found in Embase and Medline. Six references were found in reference citations. In total, 40 articles were retrieved. Two articles were found to be duplicate publications (Rithalia and Gonsalkorale, 1998; Rithalia et al., 2000).

Table 1
Summary of included and excluded studies

| | Pubmed | Cinahl | Central | Embase | Medline | Reference lists |
|---|---|---|---|---|---|---|
| Search result | 83 | 68 | 24 | 3 | 68 | – |
| Excluded | 52 | 48 | 7 | 3 | 39 | – |
| Included | 31 | 20 | 17 | 0 | 29 | 6 |

Table 2
Search term used in Pubmed database

| Search terms | | Hits |
|---|---|---|
| 1. Pressure ulcer | | |
| Mesh terms | Pressure ulcer | 9503 |
| Text words | Bed( )sore(s)/decubitus ulcer(s)/pressure sore(s) | |
| 2. Prevention | | |
| Mesh terms | Primary prevention/accident prevention | 843,249 |
| Sub-headings | Prevention and control | |
| Text words | Prevention/preventive measures/prophylaxis | |
| 3. Alternating pressure air mattress | | 1264 |
| Mesh terms | Beds/air/pressure | |
| Text words | Alternating(-)pressure mattress(es)/alternating(-)pressure support(s)/alternating(-) pressure overlay(s)/alternating(-)air mattress(es)/alternating(-) pressure air mattress(es)/alternating(-)pressure system(s)/alternating pressure surface(s)/ alternating(-)air system(s)/alternating bed(s)/ alternating dynamic mattress(es)/ alternating dynamic system(s)/alternating dynamic bed(s)/ APAM(s)/Pegasus/ Nimbus | |
| Combination 1 and 2 and 3 | | 83 |

The study by Rithalia et al. (2000) was included since it reported more extensive results. Two other articles (Gebhardt et al., 1996; Gebhardt, 1994) described the same study. The article by Gebhardt et al. (1996) was included because it reported the study in greater detail. Four references dealt with the same study (Nelson et al., 2003; Nixon et al., 2006a, b; Iglesias et al., 2006). Nixon et al. (2006b) was included as it described the study more extensively. In total, 35 studies were selected for review, of which 34 were published in English and one in German (Roales-Welsch et al., 2000). The studies included were RCTs ($n = 19$), a quasi-RCT ($n = 1$), experimental studies in laboratory setting ($n = 12$), a prospective study ($n = 1$), a retrospective study ($n = 1$), and a cost-effectiveness study ($n = 1$). The main outcome measures of the retrieved publications were: effectiveness of APAMs, comfort, cost, and mechanical reliability.

### 3.1. Methods: approaches and criticism

#### 3.1.1. Design

The majority of the included studies were RCTs and experimental studies. In 18 RCTs, the statistical power was not calculated or was insufficient (Tables 3 and 5). Randomisation was unclear or inadequate in 11 trials and in four RCTs baseline characteristics were not compared (Tables 3 and 5). The follow-up period of the RCTs evaluating the effectiveness of APAMs ranged from 1 week to 3 months (Table 3). Some RCTs were cross-over RCTs or quasi-RCTs (Table 5). Experimental studies in a laboratory setting are not an ideal reflection of clinical practice. They were executed in strictly controlled circumstances. Only a small number of participants were included, ranging from 10 to 57. In nine experimental studies, only healthy participants were included (Table 4).

#### 3.1.2. Outcome measures

To measure the effectiveness of APAMs, three principal outcome measures were used: pressure ulcer incidence, contact interface pressure (CIP), and blood perfusion. In the RCTs, the incidence of pressure ulcers was evaluated (Table 3). However, Bliss (1995), Price (1990), and Withney (1984) evaluated the changes in pressure areas. Certain trials included grade 1 pressure ulcers in the outcome measure, other trials did not.

CIP measurements determine the pressure between patient and mattress. Maximum, minimum, and mean CIP were the most frequently used outcome measures

Table 3
Summary of included randomised controlled trials regarding the effectiveness of APAMs for the prevention of PU

| Study | Setting and population | Follow-up | Intervention | Main outcome measure | Results | Methodological remarks |
|---|---|---|---|---|---|---|
| Andersen et al. (1982) | • Acute care<br>• At risk based on a self-developed risk-assessment scale<br>• No PU on admission | 10 days | • APAO: longitudinal air cells, two-cell cycle, 10′ cycle ($n = 200$)<br>• Standard hospital mattress ($n = 200$)<br>• Water mattress ($n = 200$) | PU incidence (skin break down) | • APAO: 4.2% (7/166)<br>• Standard hospital mattress: 13% (21/161)<br>• Water mattress: 4.5% (7/155)<br>• Significantly fewer PUs on APAO than on standard mattress ($P < 0.01$) | • Unclear randomisation<br>• 118 patients dropped out |
| Aranovitch et al. (1999) | • Surgery with general anaesthesia of $\geqslant 4$ h<br>• No PU on admission | 7 days | • APAR during and after surgery: $>2500$ small air cells; $<5'$ cell cycle ($n = 112$)<br>• Gel mattress during surgery and standard mattress thereafter ($n = 105$) | PU incidence (grade 1–4) | • APAR: 1% (1/112)[a] (caused by foreign body, not regard as related to mattress)<br>• Conventional management: 8.75% (7/105)[a]<br>• Significantly less PUs on APAR ($P = 0.005$) | • No power calculation<br>• Randomisation by week |
| Bliss (1995) | • Long-term care elderly<br>• Patients with grade 2 or 3 PU (no superficial sores $>5$ cm and discoloured areas $>2$ cm) | 17.7 days (mean) | • APAO: 14 air cells of 10 cm, two-cell cycle of 10′ ($n = 71$)<br>• CLP-supports: 3 foam mattresses ($n = 151$); water mattress ($n = 32$); 2 hollow fibres mattresses ($n = 104$)<br>• Standard hospital mattress ($n = 99$) | Deterioration of pressure areas to the extent that trial should be stopped | • APAO: 13%[b]<br>• CLP-supports: foam mattresses: 35%, water mattress: 47%, hollow fibre mattresses: 52%<br>• Standard hospital mattress: 44%<br>• Significantly fewer trials on APAO stopped | • No power calculation<br>• Flawed randomisation<br>• Not all mattresses were in trial at the same time<br>• Data analysed by mattress trial, not by patient |
| Conine et al. (1990b) | • Chronic neurological condition<br>• 18–55 years<br>• Norton score $\leqslant 14$<br>• No PU for $\geqslant 14$ days prior to study | 3 months | • APAO: 10 cm air cells, two-cell cycle ($n = 93$)<br>• Hollow fibres overlay ($n = 94$)<br>• Patients were turned every 2–3 h on both mattresses | PU incidence (grade 1–4) | • APAO: 54% (37/72)<br>• Hollow fibres overlay: 59% (45/76)<br>• No significant differences | • No power calculation<br>• Unclear randomisation<br>• 39 patients dropped out |

Table 3 (*continued*)

| Study | Setting and population | Follow-up | Intervention | Main outcome measure | Results | Methodological remarks |
|---|---|---|---|---|---|---|
| Daechsel and Conine (1985) | • Long-term care hospital<br>• Chronic neurological condition<br>• 19–60 years<br>• High risk for PUs based on Norton score and judgement of team<br>• No PU $\leqslant$2 weeks prior to study | 3 months | • APAO: 10 cm air cells, two-cell cycle ($n = 16$)<br>• Hollow fibres overlay ($n = 16$)<br>• Patients were turned every 3–4 h on both mattresses | PU incidence (grade 1–4) | • APAO: 25% (4/16)<br>• Hollow fibres overlay: 25% (4/16)<br>• No significant differences | • No power calculation<br>• Unclear randomisation |
| Exton-Smith et al. (1982) | • Geriatric wards, fractured femoral neck fracture in orthopaedic wards, long-stay patients<br>• Norton score $\leqslant$14<br>• No PU$\geqslant$grade 2 | 14 days | • APAR 1: double-layered, three-cell cycle of 7.5′ ($n = 31$)<br>• APAR 2: single layered, three-cell cycle, no further details given ($n = 35$) | PU incidence (grade 2–4) | • APAR 1: 16% (5/31)<br>• APAR 2: 39% (12/31)<br>• Significantly fewer PUs on APAR 1 ($p < 0.001$) | • No power calculation<br>• Flawed randomisation<br>• 4 patients discarded from analysis |
| Gebhardt et al. (1996) | • Intensive care unit<br>• Norton score $\leqslant$13<br>• No PU on admission | 11.5 days (mean) | • APAMs: 5 different types of APARs and 2 types of APAO ($n = 23$)<br>• CLP-supports: water, foam, static air, hollow fibre, gel, low-air-loss, l ($n = 20$)<br>• If PU deteriorated, APAM was replaced by more sophisticated type of same group | PU incidence | • APAR or APAO: Grade 1: 4% (1/23)<br>• CLP support: Grade 1: 15% (3/20); Grade 2–4: 40% (8/20)<br>• Significant fewer PUs on APAMs | • Flawed randomisation<br>• Power calculation after inclusion of 30 patients |
| Hampton (1997) | No details given | Not reported | • APAR 1: double-layered, three-cell cycle of 7.5′, zero pressure 15% of the time[b]<br>• APAR 2: double-layered, three-cell cycle of 7.5′, zero pressure 20% of the | PU incidence | No patients developed a PU on both mattresses | • No power calculation<br>• Unclear randomisation<br>• No baseline comparison |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | time ($n = 36$) | | | |
| Nixon et al. (2006b) | • Vascular, orthopaedic, medical, or care of elderly people wards<br>• ⩾55 years<br>• Admitted in previous 24 h<br>• Expected length of stay ⩾7 days<br>• No PU ⩾grade 3 on admission | 12.2 days (mean) | • APAR: two-, three-, or four-cell, cell cycle of 7.5′–30′, cell height min.: 19.6, cell height max.: 29.4 ($n = 982$)<br>• APAO: two-, three-, or four-cell, cell cycle of 7.5′–30′, cell height min.: 8.5, cell height max.: 12.25 ($n = 989$) | PU incidence (grade 2–4) | • APAR: 10.3% (101/982)<br>• APAO: 10.7% (106/989)<br>• No significant difference | • Power calculation not completely clear |
| Price et al. (1999) | • Fractured neck of femur<br>• Medley score >25<br>• >60 years | 14 days | • APAR: double-layered, two-cell cycle of 10′, sensor + alternating cushion ($n = 40$)<br>• CLP air mattress + cushion ($n = 40$) | PU (grade 1–4) pre-OP, 7d post-OP and 14d post-OP | • APAR: admission: 33% (13/40); pre-OP: 22% (8/37); 7d post-OP: 16% (5/31); 14d post-OP: 15%(4/26)<br>• CLP-mattress: admission: 35% (14/40); pre-OP: 19% (7/36); 7d post-OP: 19% (6/32); 14d post-OP: 21% (5/24)<br>• No significant differences in occurrence and severity of PU at any time point or in terms of progression | • Insufficient power<br>• 50 patients dropped out<br>• Patients with a PU at admission were not excluded.<br>• Results may be influenced by the treatment protocol. |
| Sideranko et al. (1992) | • Surgical intensive care units<br>• ⩾48 h stay<br>• No PU on admission | 9.4 days (mean) | • APAO[c] (Lapidus Airfloat System®) ($n = 20$)<br>• Static air mattress ($n = 20$)<br>• Water mattress ($n = 17$) | PU incidence (grades not reported) | • APAO: 25% (5/20)<br>• Static air mattress: 5% (1/20)<br>• Water mattress: 12% (2/20)<br>• No significant differences | • No power calculation<br>• Unclear randomisation |
| Stapleton (1986) | • Fractured femur<br>• Female; ⩾65 years<br>• Norton score ⩽14<br>• No PU on admission | Not mentioned | • APAO[c] (Large Cell Ripple, Talley®) ($n = 32$)<br>• Polyether foam mattress ($n = 34$)<br>• Hollow fibre mattress ($n = 34$) | PU incidence (grade 2–4) | • APAO: 34% (11/32)<br>• Polyether foam mattress: 41% (14/34)<br>• Hollow fibre mattress: 35% (12/34)<br>• No significant differences | • No power calculation<br>• Flawed randomisation<br>• Only baseline comparison of age and Norton scores |
| Taylor (1999) | • Hospital inpatients<br>• ⩾16 years | | • Integrated APAR + alternating | PU incidence | • Integrated APAR: 0% (0/22) | • Insufficient power |

Table 3 (*continued*)

| Study | Setting and population | Follow-up | Intervention | Main outcome measure | Results | Methodological remarks |
|---|---|---|---|---|---|---|
| | • At risk based on medical condition (not specified)<br>• No PU on admission | Until discharge or death | cushion: double-layered, 19 cells each, three-cell cycle of 7.5′ ($n = 22$)<br>• APAR: two-cell cycle of 10′ + pressure relieving cushion | | • APAR: 9% (2/22): 1 non-blanchable erythema and 1 superficial break down<br>• No significant difference | |
| Vanderwee et al. (2005) | • Surgical, internal or geriatric wards<br>• 2 methods for risk assessment randomly used: Braden score $<17$ or non-blanchable erythema<br>• No PU $\geqslant$ grade 2 on admission | Not mentioned | • APAO: 20 air cells, two-cell cycle of 10′, manually adjusting pressure ($n = 222$)<br>• Visco-elastic foam mattress ($n = 225$) | PU incidence (grade 2–4) | • APAO: 15.6% (34/222)<br>• Visco-elastic foam mattress: 15.3% (35/225)<br>• No significant differences | • Insufficient power |
| Withney et al. (1984) | • Medical-surgical wards<br>• In bed for $\geqslant$20 h a day<br>• Identified by researchers or nursing staff as potential subjects<br>• Most patients had relatively little skin break down on admission | 8 days (mean) | • APAR: 134 air cells, 7 cm diameter, 3′ cell cycle ($n = 25$)<br>• Polyurethane foam mattress ($n = 26$)<br>• On both mattresses patients were turned every 2 h | Changes in skin condition | • APAR: 20% better, 60% same, 20% worse<br>• Polyurethane foam mattress: 19.2% better, 57.7% same, 23.1% worse | • No power calculation<br>• Unclear randomisation<br>• No baseline comparison |

PU: pressure ulcer; CLP: constant-low-pressure; APAM: alternating pressure air mattress; APAR: alternating pressure air replacement; APAO: alternating pressure air overlay; Post-OP: post-operatively.

[a]Percentages reported in the article do not match with the reported numbers.

[b]Numbers not reported.

[c]Type of APAO not specified.

Table 4
Summary of experimental studies evaluating APAMs by CIP measurements and blood perfusion measurements

| Study | Participants | Measurements | Instrument | Intervention | Results |
|---|---|---|---|---|---|
| Clark and Rowland (1989) | Young student volunteers ($n = 10$) and elderly hospital patients ($n = 20$) | • Mean maximum, minimum, and total CIP<br>• Location: sacrum | SCP-Monitor® consisting of a 2 cm diameter hydraulic sensor | • APAR: double-layered, three-cell cycle, 7.5′ cell cycle<br>• Foam mattress<br>• Position: supine | • Significant higher maximum CIP and lower minimum CIP on APAR<br>• No difference between mean total CIP<br>• Among elderly significant higher mean maximum CIP on both mattresses and mean total CIP on foam mattress |
| Goetz et al. (2002) | Veterans with spinal cord injuries ($n = 15$) | • Minimum, maximum and average CIP, and CIP range<br>• Location: sacrum | Force Sensing Array system® consisting of 225 pressure transducers on a flexible 48 × 48 cm mat | • APAR 1: double-layered, two-cell cycle of 10′, sensor<br>• APAR 2: double-layered, three-cycle of 7.5′<br>• Position: supine and 45° upright | • Maximum, average CIP, and CIP-ranges significantly higher on APAR 2 in both supine and upright position<br>• Minimum CIP significantly lower on APAR 2 in supine position<br>• Significantly higher CIP in 45° position |
| Hickerson et al. (2004) | Healthy subjects ($n = 19$) | • Mean CIP<br>• Location: head, torso, hips, legs, and feet | Numotech Force Management System® 20 × 48 sensors on a 74″ × 42″ mat | • Standard hospital mattress<br>• Low air-loss mattress<br>• Air-fluidized bed<br>• APAR: double-layered, three-cell cycle of 7.5′<br>• Position: supine | • Total surface pressure values of the anatomical regions of the body lower on the APAR than on the other three mattresses |
| Jakobsen and Christensen (1987) | Healthy, normal-weight volunteers ($n = 12$) | • $tcPCO_2$<br>• Location: sacrum | • Clarktype oxygen sensor (E5250) measuring 14 × 8 mm and a TCM-1 oxygen monitor (Radiometer) | • Standard hospital mattress<br>• Sheep skin<br>• Water mattress<br>• Hollow fibre mattress<br>• APAO: longitudinal air cells, two-cell cycle of 5′<br>• Position: supine | • Significantly higher $tcPO_2$ on all mattresses compared with standard hospital mattress<br>• On deflated APAO significantly higher $tcPCO_2$ than on other mattresses<br>• $tcPO_2$ changes between total anoxia and almost full oxygenation on APAM |
| Mayrovitz and Smith (1999) | Post-menopausal women ($n = 20$) | • Skin temperature<br>• Skin blood perfusion before (15′) and during hip-down loading (60′)<br>• Location: proximal trochanter | • Small thermocouple temperature sensor<br>• Laser Doppler blood perfusion probe (P-440 Softlflex®) | • Gel mattress<br>• APAO: >2500 small air cells; <4′ cell cycle<br>• Position: 15′ supine position (unloaded) and 60′ lateral position (loaded) | • Skin temperature increased on both surfaces in lateral position<br>• On APAO progressive and significant increase in blood perfusion from the first to the last 15′ interval during lateral position and exceeded significantly pre-load baseline by the end<br>• No significant correlation between skin temperature changes and blood perfusion |

Table 4 (*continued*)

| Study | Participants | Measurements | Instrument | Intervention | Results |
|---|---|---|---|---|---|
| Pring and Millman (1998b) | Healthy volunteers ($n = 20$) | • Mean CIP for 30′ period<br>• Location: heels | Oxford Pressure Monitor MK 2® | • APAR 1: double-layered, two-cell cycle of 10′, sensor<br>• APAR 2:double-layered, three-cell cycle of 7.5′<br>• APAR 3: four-cell cycle, 28 air cells<br>• Position: supine | • No significant difference between APARs 1 and 3; APAR 2 had significantly higher CIPs than APARs 1 and 3 |
| Rithalia et al. (2000) | Healthy volunteers ($n = 15$) | • Mean maximum and minimum CIP<br>• PRI<br>• Mean maximum $tcPCO_2$ and minimum $tcPO_2$ ($n = 11$)<br>• Mean area under $tcPO_2$ /$tcPCO_2$ curves<br>• Location: (CIP) sacrum, heel, left trochanter, buttock; ($tcPO_2$/$tcPCO_2$) sacrum | • CIP: Oxford Pressure Monitor®<br>• Transcutaneous monitoring system (Kontron Instruments Ltd.) | • APAO 1: 20 air cells, two-cell cycle of 10′, manually adjusting pressure<br>• APAR 2: double-layered, 20 air cells, two-cell cycle of 7.5′, sensor<br>• APAR 3: double-layered, 18 air cells, two-cell cycle of 12′<br>• APAR 4: 20 air cells, three-cell cycle of 14′<br>• Position: supine, left lateral, 45° upright | • Maximum CIP at the sacrum significantly lower on APAO 1 and APAM 2<br>• Minimum CIP at sacrum significantly higher on APAR 4<br>• APAMs 1, 2 and 3 significant greater pressure relief $<10$ mmHg at sacrum than APAM 4<br>• APAMs 1 and 2 better $tcPCO_2$ and $tcPO_2$ values at the sacrum |
| Rithalia and Gonsalkorale (2000) | Healthy adult postgraduate students ($n = 11$) | • Mean maximum and minimum CIP<br>• PRI<br>• Mean maximum $tcPCO_2$ and minimum $tcPO_2$<br>• Mean area under $tcPO_2$ /$tcPCO_2$ curves<br>• Location: (CIP) sacrum, heel, left trochanter, buttock; ($tcPO_2$ /$tcPCO_2$) sacrum | • CIP: Oxford Pressure Monitor®<br>• Transcutaneous monitoring system (Kontron Instruments Ltd.) | • APAR 1: double-layered, 18 air cells, three-cell cycle of 7.5′<br>• APAR 2: 20 air cells, two-cell cycle of 10′<br>• Position: supine, left lateral, 45° upright | • Maximum CIP on the sacrum lower on APAR 2<br>• CIP on the sacrum longer $<10$, 20 and 30 mmHg on APAR 2<br>• Lowest $tcPO_2$ on APAR 1 |
| Rithalia (2004) | Healthy volunteers ($n = 10$) | • Mean maximum and minimum CIP<br>• PRI<br>• Mean maximum $tcPCO_2$ and minimum $tcPO_2$ | • CIP: Oxford Pressure Monitor®<br>• Transcutaneous monitoring system (TCM3®)<br>• Skin blood perfusion: LDF monitor: Softlo, | • APAR 1: 19 air cells, 10′ cell cycle, low air pressure heel zone 5′ cell cycle, automatic pressure control<br>• APAR 2: double-layered, 20 air cells, two-cell cycle of 10′, 5 Heelguard cells, sensor | • Lower minimum CIP at the heels on APAR 2<br>• CIP at the sacrum was held significantly longer $<30$ mmHg on APAR 1<br>• Lowest $tcPO_2$ was higher on APAR 1<br>• Skin blood perfusion significantly greater on the APAM 2 |

| | | | | | |
|---|---|---|---|---|---|
| | | • Mean area under $tcPO_2$ /$tcPCO_2$ curves<br>• Mean maximum skin blood perfusion<br>• Mean area under skin blood perfusion-time curves<br>• Location (CIP) sacrum, heel, left trochanter, buttock; ($tcPO_2$/$tcPCO_2$) sacrum; (LDF) heel | BPM2® | • Position: supine, left lateral, 45° upright | |
| Roales-Welsch et al. (2000) | Adult participants ($n = 19$) | • Maximum, minimum and mean CIP<br>• Location: os occipital, scapula, sacrum, heel | Pressure Monitor Mk3® consisting of 12 sensors on a 16 × 23 cm mat | • 5 APARs with two-cell cycles: APAR 1:19 air cells, sensor; APAR 2:17 air cells of 13 cm, 10′ cylce; APAR 3: 20 air cells of 13.5 cm, 10′ cycle, sensor; APAR 4: 20 air cells of 20 cm, 10′ cycle; APAR 5: 20 air cells of 15 cm, 10′ cycle<br>• Position: supine | • Mean maximum CIP varies from 39.8 to 57.8 mmHg over 12′ on the different APARs<br>• APAR 3 significant higher CIP than APARs 4, 2, and 1; but lower CIP than APAM 5 |
| Sideranko et al. (1992) | Surgical intensive care patients ($n = 57$) | • Mean CIP<br>• Location: heel, sacrum | Fluid filled IV bag, connected to hemodynamic monitors | • APAO: Lapidus Airfloat System®($n = 20$)<br>• Static air mattress ($n = 20$)<br>• Water mattress ($n = 17$)<br>• Position: supine, semi-Fowler 45° | • Significant higher mean CIP on APAO regardless of position or location |
| Stewart et al. (1990) | Healthy volunteers ($n = 20$) | • Mean maximum CIP at cell inflation and minimum CIP at cell deflation<br>• Location: left trochanter | Bladder type pressure transducer (PSP-1®) | • Standard hospital mattress<br>• APAO: 10 cm air cells; two-cell cycle<br>• Position: left lateral | • Significant lower maximum and minimum CIP on the APAO |
| Swain et al. (1992) | Healthy volunteers >70 years ($n = 10$) | • Maximum, minimum and average CIP<br>• Location: heels, sacrum, ischial tuberosities | Oxford Pressure Monitor® consisting of 3 × 4 sensors | • APAR 1: double-layered, 20 air cells, two-cell cycle of 10′, sensor<br>• APAR 2: double-layered, three-cell cycle of 7.5′<br>• Position: semi-recumbent 45°, lateral | • On APAR 1 lower maximum and higher minimum CIP<br>• No significant difference in average pressures |

APAM: alternating pressure air mattress; APAR: alternating pressure air replacement; APAO: alternating pressure air overlay; CIP: contact interface pressure; LDF: laser Doppler fluxmetry; PRI: pressure relief index (duration CIP <30, 20 and 10 mmHg over 60').

(Table 5). Mattresses with lower CIP-values are considered to be more effective (Webster, 1991). Another outcome measure was the pressure relief index (PRI), which is the length of time that APAMs generate CIP below thresholds of 10, 20, and 30 mmHg during 1 h (Rithalia et al., 2000). Considering that APAMs generate alternating high and low CIPs, it is not clear how mean, maximum, or minimum CIP must be interpreted (Clark, 1994; Swain and Bader, 2002). No clinical or physical evidence is found in the literature for thresholds of 10, 20, or 30 mmHg. To date, it is unknown which level of CIP can be considered as adequate to prevent pressure ulcers (Krouskop et al., 1990).

To measure blood perfusion, transcutaneous oxygen ($tcPO_2$) and carbon dioxide ($tcPCO_2$) were assessed. Measurements of $tcPO_2$ are an estimate of the partial pressure of arterial oxygen and thus of skin blood flow (Neander and Birkenfeld, 1990). Another technique used to measure blood perfusion was laser-doppler fluxmetry (LDF). The minimum oxygen supply necessary to prevent pressure ulcers remains unknown (Neander and Birkenfeld, 1991).

The comfort of APAMs was generally evaluated by means of non-validated questionnaires or by visual analogue scales (VASs) (Table 5).

### 3.2. Effectiveness of APAMs

#### 3.2.1. Pressure ulcer incidence

Table 3 presents 15 RCTs comparing the incidence of pressure ulcers on APAMs with those on other mattresses or on other types of APAMs. Andersen et al. (1982) reported a significantly lower pressure ulcer incidence on an APAM than on a standard hospital mattress. In 10 trials, APAMs were compared with several constant-low-pressure mattresses. In five RCTs, no statistical difference was found between APAOs and air mattresses (Sideranko et al., 1992), water mattresses (Sideranko et al., 1992), hollow fibre mattresses (Conine et al., 1990b; Daechsel and Conine, 1985; Stapleton, 1986), and foam mattresses (Vanderwee et al., 2005; Stapleton, 1986). In two trials, no difference was found between APARs and air mattresses (Price et al., 1999) and between APARs and foam mattresses (Withney et al., 1984). In contrast, three studies reported that APAOs and/or APARs were significantly more beneficial than constant-low-pressure mattresses (Aranovitch et al., 1999; Bliss, 1995; Gebhardt et al., 1996).

Four RCTs assessed the effectiveness of different APAMs. Exton-Smith et al. (1982) found a double-layered three-cell APAR to be more effective than a single-layered one. Taylor (1999) compared an integrated three-cell APAR and cushion with a two-cell APAR and pressure relieving cushion. In both groups, few patients developed a pressure ulcer. In the study by Hampton (1997), both on a three-cell APAR and on its enhanced version, no patients developed a pressure ulcer. Nixon et al. (2006b) found a nearly similar pressure ulcer incidence between APARs and APAOs.

In a retrospective study, Still et al. (2003) evaluated the pressure ulcer incidence of burned patients nursed on a double-layered, three-cell APAR compared with a standard hospital mattress. The authors concluded that the APAR was effective in reducing the pressure ulcer incidence in burned patients.

#### 3.2.2. Contact interface pressure and blood perfusion

Table 4 shows 13 studies in which CIP or blood perfusion was used to assess the effectiveness of APAMs. Two studies compared an APAM with a standard hospital mattress. Stewart et al. (1990) reported significant lower CIPs for the APAO. Jakobsen and Christensen (1987) showed a significantly higher $tcPO_2$ on the APAO.

In four studies, the effectiveness of an APAM was compared with various constant-low-pressure surfaces. Clark and Rowland (1989) found that an APAR generated higher maximum and lower minimum CIPs than a foam mattress. Sideranko et al. (1992) reported significantly higher mean CIPs for APAOs than for water or static air mattresses. Jakobsen and Christensen (1987) found significantly higher $tcPO_2$ values on an APAO when deflated than on a water or hollow fibre mattress. Mayrovitz and Smith (1999) observed a significant progressive increase in blood perfusion on an APAO, which was not the case on a gel mattress.

Seven studies compared different types of APAMs. Goetz et al. (2002), Rithalia and Gonsalkorale (2000), and Swain et al. (1992) compared two-cell APARs with three-cell APARs. Lower maximum CIPs were observed in two-cell APARs. Rithalia and Gonsalkorale (2000) found higher PRI and $tcPO_2$ levels on two-cell APARs. Pring and Millman (1998b) assessed two-, three-, and four-cell APARs. They reported significantly higher mean CIPs on a three-cell APAR. Rithalia et al. (2000) found significantly longer pressure relief beneath 10 mmHg on two-cell APAMs than on three-cell APAM. However, there were significant differences in maximum CIP and transcutaneous gas values between two-cell APAMs. Rithalia (2004) evaluated two two-cell APARs with a special heel zone, which resulted in significant differences in minimum CIP during the deflation phase. There was also a difference in blood perfusion between the different APARs. Roales-Welsch et al. (2000) assessed five different two-cell APARs, which varied in the number and size of cells. There were significant differences in CIPs between these two-cell APARs (Table 4).

### 3.3. Comfort

The comfort of the mattresses was discussed in four RCTs comparing the effectiveness of APAMs with

Table 5
Summary of included randomized controlled trials regarding the comfort or cost of APAMs for the prevention of PU

| Study | Setting and population | Follow-up | Mattresses | Main outcome measure | Instruments | Results | Methodological remarks |
|---|---|---|---|---|---|---|---|
| Ballard (1997) | • Nursing homes<br>• No existing PU<br>• <150 kg | Evaluation after 3 nights | • APAR 1: double-layered , 10′ cell cycle; sensor<br>• APAR 2: 28 air cells; four cell cycle of 30′ | • Comfort<br>• Quality of sleep | • 15 point standardized questionnaire (comfort and quality of sleep) ($n = 10$)<br>• VAS (comfort) ($n = 10$) | • Majority (8/10) preferred APAR 2 for both quality of sleep and comfort<br>• VAS indicated strong preference for APAR 2 ($p = 0.019$)<br>• Quality of sleep: both APARs caused some patients to wake (APAR 1: 4/10; APAR 2: 2/10); some patient reported that the APARs prevented them getting to sleep (APAR 1: 4/10; APAR 2: 3/10) | • RCT, cross-over<br>• No power calculation<br>• Very small sample<br>• Questionnaire not validated<br>• VAS |
| Chaloner and Cave (2000) | • Community care<br>• >16 years<br>• No existing PU<br>• At risk according to the Walsall Community Risk Score Calculator | Proposed: 14 days | • APAR 1: two-cell cycle of 12′ ($n = 22$)<br>• APAR 2: two-cell cycle of 12′;differed in minor aspects of APAR 1: material of mattress cover and upper layer of inflatable cells, mattress width ($n = 22$) | • Comfort | • Questionnaire (not specified) | • On APAR 1 all patients ($n = 14$) were comfortable and on APAR 2 15/21 | • Quasi-RCT: random allocation to APARs according to availability of mattresses<br>• Underpowered<br>• 9 patients dropped out |
| Conine et al. (1990a) | • Chronic neurological condition<br>• 18–55 years<br>• Norton score ⩽14 | 3 months | • APAO: 10 cm air cells, two-cell cycle<br>• Hollow fibres overlay | • Cost<br>• Acceptability | • Measure of cost: depreciation; maintenance and operation; repair<br>• Questionnaire (acceptability) ($n = 40$) | • Total overall annual cost of APAO was 54% more than that of hollow fibre overlay<br>• Patients' satisfaction similar for both overlays (APAO: 18/20; Hollow fibre 17/20); greater comfort on hollow fibre overlay (20/20) than on APAO (8/20); majority disturbed by noise of APOA (12/20) (hollow fibre 0/20) | • No power calculation<br>• No baseline comparison |

Table 5 (*continued*)

| Study | Setting and population | Follow-up | Mattresses | Main outcome measure | Instruments | Results | Methodological remarks |
|---|---|---|---|---|---|---|---|
| Grindley and Acres (1996) | • PU ⩾grade 2 or no PU but Waterlow score ⩾15<br>• <190 kg | Evaluation during 3 nights | • APAR 1: two-cell cycle of 10′, sensor ($n = 20$)<br>• APAR 2: double-layered, three-cell cycle of 7.5′ ($n = 20$) | • Comfort<br>• Quality of sleep | • Mattress preference questionnaire ($n = 16$)<br>• Quality of sleep questionnaire | • 10 patients preferred APAR 1 ($p = 0.04$)<br>• The cells of APAR 2 appeared to be to hard<br>• Better and more consistent night's sleep on APAR 1 than on APAR 2 for all aspects of sleep quality and comfort tested | • RCT, cross-over<br>• No power calculation<br>• Block randomisation<br>• Questionnaires not validated<br>• 4 patients dropped out |
| Pring and Millman (1998a, b) | • Rehabilitation units<br>• Neurological disorders<br>• 16–65 years<br>• Waterlow score ⩾15<br>• No existing PU ⩾grade 2 | Evaluation after 1 week | • APAR 1: double-layered, 10′ cycle, sensor<br>• APAR 2: double-layered, three-cell cycle of 7.5′<br>• APAR 3: 28 cell, four cell cycle | • Comfort | • VAS (pain and comfort) ($n = 40$)<br>• Short form of McGill pain questionnaire (pain and comfort) ($n = 40$) | • Less pain on APAR 1 and 3 ($p < 0.05$; $p < 0.01$)<br>• APAR 3 more comfortable ($p < 0.01$) and caused less sleep disturbance ($p < 0.05$)<br>• APAR 3 less movement than APAR 2 ($p < 0.01$)<br>• APAR 1 quieter than APAR 2 ($p < 0.01$) | • No power calculation<br>• No baseline comparison<br>• Not reported how many patients per APAR were evaluated<br>• VAS<br>• Short form of McGill questionnaire |

APAM: alternating pressure air mattress, APAR: alternating pressure air replacement, APAO: alternating pressure air overlay, PU: pressure ulcers, VAS: visual analogue scale.

constant-low-pressure mattresses. Andersen (1982) noted that some patients found the fully inflated tubes hard to lie on and also had complaints about noise. Bliss (1995) found that very few patients complained about the two types of mattresses used in this study as being uncomfortable. Price et al. (1999) reported that comfort scores, using a VAS, were higher for the constant-low-pressure air mattress than for the APAR. However, the difference was not significant. Nixon et al. (2006b) assessed the patient acceptability of APARs and APAOs. The number of patients that requested a change of mattress due to dissatisfaction was significantly higher on the APAO than on the APAR. When questioned about acceptability, more patients reported problems on the APAO than on the APAR. These problems related to mattress comfort, temperature, getting into and out of bed, movement while in bed, mattress motion, and sleep.

In three laboratory studies by Rithalia, participants were asked about their perceived comfort level. One study reported that participants preferred the double-layered two-cell APAM (with a sensor which automatically changes the inflation) over two other two- and three-cell APAMs without sensor (Rithalia et al., 2000). The next study found that seven of the 11 participants perceived a three-cell APAR as uncomfortable (Rithalia and Gonsalkorale, 2000). In another study, some participants (2/10, 3/10) experienced both APARs as uncomfortable when used in an inclined backrest position (Rithalia, 2004).

Conine et al. (1990a), using questionnaires, assessed the acceptability of an APAO and hollow fibre overlay. In general, almost all patients were satisfied with their overlay. The hollow fibre overlay, however, offered a significantly greater level of comfort. The majority of the patients were disturbed by the noise of the APAO (Table 5).

In four RCTs, the main objective was to compare the comfort level of different APARs (Table 5). The pilot study of Ballard (1997) into both quality of sleep and comfort indicated a preference for a four-cell APAR with a 30 min cell cycle over a two-cell APAR with a 10 min cycle. Grindley and Acres (1996) reported that a two-cell APAR was superior to a three-cell APAR. Pring and Millman (1998a) found that the two- and four-cell APARs performed better than the three-cell APAR with regard to pain relief, mattress movement, and noise. The results on comfort and sleep disturbance indicated that the four-cell APAR was significantly better. In the study by Chaloner and Cave (2000), most patients found themselves comfortable both on the original and on the enhanced two-cell APAR.

### 3.4. Mechanical reliability and user errors

APAMs consist of a mattress connected to an electrically driven pump. As with virtually any mechanical device, they can be susceptible to breakdowns and defects. Stapleton (1986) reported that 45 large-cell APAOs required 50 pump repairs and 90 repairs of material over a 12-month period. Gebhardt et al. (1998) conducted a study lasting 1 year to monitor the incidence of mechanical breakdown and mismanagement of APAOs. A total of 53 overlays (six types) experienced 69 mechanical failures and seven cases of physical damage. There were 56 errors in management and five cases of design features contributing to equipment mismanagement. The authors concluded that although some APAOs perform better than others, mechanical unreliability remains a problem for most. Conine et al. (1990a) reported that significantly more nurses were concerned with the APAOs' need for frequent and careful monitoring and repair than with the hollow fibre overlays. Nixon et al. (2006b) listed more technical problems on APAOs (207 problems/131 APAOs) than on APARs (172 problems/92 APARs). Most commonly reported problems were: the mattress had deflated or lost its required pressure, the mains plug was defective or there were problems with the settings and during cardiopulmonary resuscitation. Nixon et al. (2006b) considered not turning on the electricity supply also as a technical problem. This problem counted on both mattresses for approximately 19% of the problems (APAOs 40/207; APARs 33/172).

### 3.5. Cost

Conine et al. (1990a) reported that the annual cost of the APAO amounted to 54% more than that of the hollow fibre overlay (Table 5). Fleurence (2005) investigated the cost-effectiveness of APARs and APAOs compared with a standard hospital foam mattress. For this purpose, a decision-analytic model was constructed. Epidemiological and effectiveness data were obtained from the clinical literature. Expert opinions were used to obtain quality of life data. Costs of the mattresses were obtained from manufacturers. The results suggested that APAOs may be the most cost-effective for the prevention of pressure ulcers. Nixon et al. (2006b) assessed the cost-effectiveness of APARs compared with APAOs in patients admitted to hospital. The analysis included mattress costs, hospital costs, and pressure-ulcer-free days. The authors concluded that the APARs were associated with lower costs, mainly due to reduced length of stay in the hospital and a delay in the development of pressure ulcers.

## 4. Discussion

The main focuses of the reviewed studies evaluating APAMs were the effectiveness and the comfort of APAMs. Pressure ulcer incidence, CIP, and blood

perfusion were the most frequently used outcome measures to evaluate the effectiveness of APAMs. In general, RCTs evaluating the incidence of pressure ulcer are considered the strongest method of providing evidence about the effectiveness of APAMs (Bliss and Thomas, 1993). Based on the RCTs reviewed, an APAM seemed to be more effective than a standard hospital mattress. The RCTs comparing the effectiveness of APAMs and of constant-low-pressure mattresses resulted in conflicting evidence. It is not possible to conclude whether APAMs are more or less effective than constant-low-pressure mattresses. Based on the trials evaluating various APAMs, we are unable to conclude which type of APAM performs better. Our results are consistent with those of Cullum et al. (2006). As stated earlier, all RCTs cited in this review of the literature have methodological flaws which hamper effective comparisons. Therefore, the results must be interpreted with caution. Studies using pressure ulcers as outcome measure define pressure ulcers in different ways. Some include grade 1 pressure ulcers, others do not. Currently, there is controversy on whether non-blanchable erythema (grade 1) is to be considered as a pressure ulcer or whether only grades 2–4 should be defined as pressure ulcers? This issue should be resolved in order to allow accurate comparisons between studies.

Given the difficulties of performing RCTs in this area—such as cost, time investment, and the number of subjects needed—alternative methods of evaluating APAMs were searched and used. They include experimental studies in a laboratory setting. The most commonly used method in the experimental studies cited is the measurement of CIP. The measurement of blood perfusion is used less frequently.

The CIP and blood perfusion measurements indicated better results for APAMs than for standard hospital mattresses. However, it is not possible to formulate recommendations for clinical practice based on the studies comparing APAMs and constant-low-pressure surfaces. Studies comparing different APAMs, demonstrated better results for two-cell APAMs than for three-cell APAMs. But it must be noted that significant differences were also found between the various two-cell APAMs. Based on these results, we cannot make recommendations for clinical practice given the above critiques.

Some additional remarks are in order: CIP is measured at the surface of the skin, not in the deep tissues. Pressure in deep tissues is higher than at the skin surface (Welch, 1990). CIP is therefore only an indirect measure of the pressure in underlying tissues. Similar observations can be made regarding blood perfusion measurements. These only give an accurate indication of the blood perfusion at the skin surface. Further, CIP measurements do not take into account shearing forces as a cause of pressure ulcers.

The underlying mechanisms whereby tissue compression leads to tissue damage are still poorly understood (Bader and Oomens, 2006; Swain and Bader, 2002). Different theories involve localised ischaemia, impaired interstitial fluid flow and lymphatic drainage, reperfusion injury, and sustained deformation of cells (Bouten et al., 2003). Consequently, the exact relationship between pressure and pressure ulcers and between blood perfusion and pressure ulcers is not yet clear.

Generally, CIP measurements were carried out on healthy young volunteers. It would be interesting to contrast such measurements with those taken from elderly patients who have a loss of muscle tone and are often dealing with circulatory disorders as well. These states put the elderly at greater risk of developing a pressure ulcer (Maklebust et al., 1986). In one reviewed study, elderly subjects were included. They had higher mean CIPs than healthy volunteers (Clark and Rowland, 1989) which is consistent with a recent study (Weststrate, 2005). In healthy subjects, the blood supply to the skin can generally be restored under conditions of alternating contact pressure. This recovery however does not always occur in intensive care patients (Neander and Birkenfeld, 1990).

We are unable to make a definitive recommendation regarding the effectiveness of APAMs based on studies evaluating CIP and blood perfusion. These measurements can only suggest a hypothetical advantage or disadvantage of one mattress compared with another (Rithalia, 2004). They are not a suitable means of evaluating APAMs. CIP measurements may however be appropriate in providing guidance on the rate of speed of pressure relief on an APAM. This may be useful since relieving pressure slowly may prevent reperfusion injuries. Moreover, the tissue cannot restore itself, if an air–cell cycle is too short.

There are a number of alternative designs for studies which are less expensive and easier to execute than RCTs. A case-control study might be considered. However, it is not clear which patient characteristics have to be matched since the knowledge of risk factors and the aetiology of pressure ulcers are still too limited. These problems make it difficult to undertake well-conducted case-control studies. A pressure ulcer prevalence survey before and after the introduction of APAMs is another possibility. Such a survey is more feasible than an incidence study with a long follow-up period (De Laat et al., 2006). However, other influences will affect the results and provide less conclusive evidence and the results will be informative only if the population remains unchanged. Here too, the fact that little is known about the variables on which the population should be compared will hamper the correct interpretation of the findings. In both alternative designs, the direct causal relationship between APAMs and pressure ulcer development is not

studied. Other influences will affect the results of these studies.

Although RCTs are expensive and time consuming, they provide the strongest evidence of a causal relationship between APAMs and the development of pressure ulcers. Sufficiently large RCTs of good quality are necessary to provide evidence about the effectiveness of APAMs (Bliss and Thomas, 1993). Thus far, almost no such trials have been conducted. Additional large trials are needed to provide evidence about the effectiveness of APAMs.

Different methods were used to evaluate the comfort of APAMs. Most of these were not validated questionnaires and VASs. The VAS is used to measure subjective experiences, such as pain, fatigue, and nausea (Polit et al., 2001). However, this scale has some weaknesses: it may not produce reliable ratings across different groups of patients. This is because each patient may interpret the scale differently and for some patients the VAS is conceptually complex (Brigs and Closs, 1999). Alternative outcome measures for comfort on an APAM need to be designed and validated.

The assessed samples of patients were very small in the studies reviewed. Consequently, it is difficult to make comparisons and to draw general conclusions. It is obvious that alternating inflation and deflation of air cells may cause discomfort for some patients. We agree with Grindley and Acres (1996), who stated that less extreme changes in pressure, lower peak inflation pressures, and the ability of the mattress to automatically adjust pressure to the patient's position and weight may explain better comfort. Comfort is related to the individual characteristics of the mattress. Most important among these are that APAMs do not feel too hard or unstable and do not make much noise. Ultimately, comfort remains a subjective judgement.

Only a few studies discussed mechanical problems and user errors associated with APAMs. Special attention must be drawn to these problems since pressure ulcers can develop because of a failure in the proper functioning of APAMs. Timely and appropriate maintenance of the APAMs is necessary. Quite a number of the problems observed were caused by incorrect management of the device by nurses. This can be due to a lack of sufficient training and knowledge. Health care institutions must ascertain that nurses have the necessary knowledge to correctly use APAMs. They must provide appropriate education if this knowledge is lacking, in order to prevent or reduce technical problems attributed to nursing errors and the resulting pressure ulcers.

It is well know that the purchase cost of an APAM is higher than the cost of a constant-low-pressure mattress. It is important that health care institutions, when deciding upon the purchase of mattresses, have correct and adequate evidence about their effectiveness at hand. Therefore, further research is necessary. Based on the studies of Fleurence (2005) and Nixon et al. (2006b) it is not clear whether APAOs rather than APARs are more cost-effective. However, it is difficult to compare these studies as they use different evaluation methods.

## 5. Conclusion

This paper provides an overview of literature published on the use of APAMs as a means of pressure ulcer prevention. The literature is mainly focused on the effectiveness and comfort of APAMs. Taking into account methodological issues, we can conclude that APAMs are likely to be more effective than standard hospital mattresses. Using CIP and blood perfusion to evaluate APAMs is questionable. These measurements can only yield an assumption about the effectiveness of APAMs. Further large, high-quality RCTs are needed since they are considered the optimal method of providing evidence about the effectiveness of APAMs. Patient's comfort on an APAM might increase by reducing the differential in pressure changes and peak inflation pressure, and by employing a mattress that automatically adjusts to the patient. Better measures for comfort are needed. A number of technical problems associated with APAMs are related to nurses' improper use of the devices.

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