Comparison of Interface Pressures in the Pediatric Population Among Various Support Surfaces

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Supported in part by the National Institutes of Health, grant No. MO1-00188.

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1071-5754/2002/$35.00 + 0

21/1/127208

doi:10.1067/mjw.2002.127208

Objective: The purpose of this study was to evaluate the interface pressures under the bony prominences of children on several support surfaces to evaluate benefit, in terms of the lowest interface pressures, and cost-effectiveness.
Design: A descriptive study design was used.
Setting/subjects: A convenience sample of 54 healthy children from the community ranging in age from infancy through 16 years was enrolled through advertisements in the hospital newsletter. The study was conducted in the General Clinical Research Center located within Texas Children's Hospital, Houston, Texas.
Instruments: The instrument used to measure the interface pressures was the Mini-Texas Interface Pressure Evaluator.
Methods: A comparison was done to evaluate interface pressures under the occiput for infants to children younger than 6 years of age and under the occiput, coccyx, and heel for 6- to 18-year-olds. Five surface combinations were used for measurements: a standard hospital bed or crib mattress; mattress with Delta foam overlay; a mattress with a Gel-E-Donut pillow; a mattress with a Delta foam overlay plus Gel-E-Donut pillow; and an Efica low-air-loss bed.
Results: The standard hospital mattress yielded the highest interface pressures. The Delta Foam overlay alone or in combination with the Gel-E-Donut pillow produced the lowest occipital pressures in all age groups. The Delta foam overlay produced comparable pressures to the Efica low-air-loss bed when measuring the coccyx and heel interface pressures.
Conclusions: The Delta Foam overlay alone or in combination with the Gel-E-Donut pillow is a cost-effective and therapeutic choice for pressure reduction as demonstrated in this study of healthy children. (J WOCN 2002;29:242-51.)

Many critically ill infants and children are at risk for skin breakdown and acquire pressure ulcers. Choosing the best support surface for these infants and children can be difficult and challenging. Many of the commonly available support surfaces—low-air-loss beds, foam overlays, and gel pads—have only been studied in the adult population. In the investigators' pediatric institution, several surfaces and products are being used alone and in various combinations to try to achieve the best surface possible. The purpose of this study was to evaluate the interface pressures under the bony prominences of children of all ages and sizes (weights) on several support surfaces to determine benefit and cost-effectiveness.

LITERATURE REVIEW

Pressure ulcers are a prevalent problem not only in the adult population but also in the pediatric population. The high-risk pediatric group consists of critically ill infants and children who are immobile, experiencing respiratory compromise, and in need of nutritional support. Caring for these children can be challenging because risk factors are not well defined, although new risk assessment tools are being developed.[1] It is known that children acquire pressure ulcers in different locations than do adults; thus, they need a support surface that reduces pressure where they most need it, at the occiput. A child's head is much larger in proportion to the rest of his or her body surface area, which places the occipital region at risk for skin breakdown.[2] Several support surface products are available for children at risk for skin breakdown, but it is uncommon to find a product with research to support its effectiveness. For the majority of available support surfaces, there is no research to demonstrate the efficacy of the product with pediatric users.

A review of the adult literature revealed several studies investigating support surfaces that decrease interface pressures and are therapeutic for pressure ulcers.[3-10] No one surface has been found to consistently excel above all others under all circumstances.[11] A variety of factors need to be considered when selecting a support surface.[5,7,9-12] In 1987, in their conceptual schema for the etiology of pressure ulcers in adults, Braden and Bergstrom[13] described 2 central criteria that lead to pressure ulcer formation: the intensity and duration of pressure and tissue tolerance. Subfactors that affect the 2 main criteria include decreased mobility, activity and sensory perception, the presence of moisture, friction and shear forces, decreased nutrition, increased age, and decreased arteriolar pressure. The Braden Scale is a well-known risk assessment tool used in the adult population.

Testing Effectiveness of Support Surfaces

Most support surfaces are tested for their effectiveness by obtaining a pressure measurement under a bony prominence, such as the occiput or heel, when the person is lying on the support surface.[3,4,6-8,14] By measuring the interface pressure under a bony prominence, it is possible to determine the pressure gradient in the tissue. The pressure gradient is what drives fluid from areas of high pressure to lower pressure. The loss of interstitial fluid in a region of tissue has been hypothesized to be a major factor in the development of pressure ulcers.[15-17]

Thirty-two mm Hg is often quoted as the ideal interface pressure for support surfaces to prevent pressure ulcers. This number was originally determined in the late 19th century when Starling and other cardiovascular physiologists were developing our understanding of the cardiovascular system dynamics. The number 32 mm Hg is an average from the data of interface pressure measurements. Because this research was done with adult men, the results must be interpreted cautiously when working with the pediatric or geriatric population. Because the capillary closure pressures change with posture, age, and disease or disability, there is no specific number that will ensure that the tissue will remain viable when subjected to mechanical forces. What is desired is the lowest possible pressures so that the pressure gradients will be low and the window available to provide care is as long as possible.[15,16]

Low-air-loss Beds

The research on low-air-loss beds in children who are at risk for skin breakdown is sparse; the research in adults reflects the effectiveness of the low-air-loss beds in lowering interface pressure and treating pressure ulcers.[3,5,9,12,18] Ryan and Byrne[3] conducted a study in 1989 with 5 healthy adults and found that all 3 specialized beds studied, including a water bed, a low-air-loss bed, and an air-fluidized bed, had some benefit over a standard mattress. However, the low-air-loss bed did not achieve very low pressures under the occipital area, which has implications in pediatrics. Counsell et al[8] compared 4 support surfaces with 15 healthy adults with use of the Texas Interface Pressure Evaluator (TIPE) and found that the best surface that yielded low interface pressures was a low-air-loss bed.

Specialty Bed Research

Pediatric research by the specialty bed companies may be lacking because the number of low-air-loss beds used for pediatric clients is very small compared with the adult consumer market. The beds are designed for the adult by altering pressure within the bed sections that are divided according to an adult's body proportions. Some of the computerized low-air-loss beds that require the input of a height and weight do not have appropriate numerical options to accommodate pediatric patients. When a young child below the minimum weight is placed on the low-air-loss bed, the result may be that the child "sinks" into the cushions, which can only be corrected if a higher artificial weight is recorded into the bed computer system to inflate the cushions. The effectiveness of this compensatory strategy has an undetermined effect on the pressure-relieving capability of the bed. Low-air-loss beds are used in several pediatric facilities, often for critically ill children who cannot be turned and who may already have skin breakdown and/or pressure ulcer development. This can be a very expensive therapy depending on the effectiveness of the bed and length of time it is required for the patient.

Many critically ill infants and children are at risk for skin breakdown and acquire pressure ulcers.

Foam Overlays

Foam overlays have also been studied predominately in adults and found to be as effective as several other support surfaces, including low-air-loss beds.[4-7,9] Foam overlays are an inexpensive and effective therapy to reduce interface pressure. Krouskop et al[4] evaluated 7 surfaces with 30 adult rehabilitation patients and found that all of them were equally effective in reducing pressure under bony prominences compared with the standard mattress. Hover and Krouskop[6] compared an experimental foam overlay, the Delta foam overlay by Span-America Medical Systems (Greenville, SC), to 5 other surfaces with healthy adult subjects using the Mini-Texas Interface Pressure Evaluator (Mini-TIPE). They found that the experimental overlay's design enhanced pressure reduction and effectively produced lower interface pressures than did the other 5 surfaces. One of the few studies evaluating interface pressure with children was done in 1988 by Solis et al,[2] who studied children between the ages of 10 weeks and 13.5 years. They measured interface pressures under bony prominences of the occipital, scapula, and sacral-coccygeal area while the subjects were lying on 2-inch and 4-inch convoluted foam overlays. The highest pressures were found under the occipital areas and sacral pressures in older children. The study supported the effectiveness of either a 2- or 4-inch convoluted foam overlay to decrease the interface pressure and redistribute weight away from bony prominences. Foam overlays are commonly used today to reduce pressure for children who have limited mobility and/or sensation.

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Gel-filled Pillows

Gel-filled pillows and pads are commonly used in pediatrics, especially for the critically ill infants and children who are immobile in the pediatric and neonatal intensive care units. A search of the published literature did not reveal any studies pertaining to this therapy related to pressure reduction in adults or children. The Gel-E-Donut pillow by Children's Medical Ventures, Norwell, Mass, has known beneficial effects on head molding in neonates, but many health care professionals also use the pillow as a positioning support and pressure-reduction device under the occiput and heels to prevent pressure ulcers. In 1993 Gershan and Esterly[19] evaluated the use of a Spenco gel pad (Spenco, Waco, Tex) in the neonatal at-risk population receiving extracorporeal membrane oxygenation (ECMO) along with a positioning schedule and found during a 6-month period that pressure ulcerations were eliminated. Gel pillows are a great alternative to "home-made water pillows" that consist of ice bags filled with an undetermined amount of water and used for positioning. The gel pillows are easy to use and inexpensive. Additional research is still needed to determine the effectiveness of the gel-filled pillow as a pressure reduction device.

RESEARCH QUESTIONS

The goal of this study was to evaluate several support surfaces and/or combinations of surfaces with children of all age groups and weights by measuring the interface pressures under the bony prominences (occiput for children younger than 6 years; occiput, coccyx, and heel for children 6 to 18 years of age). A low interface pressure would indicate a decrease in risk for pediatric patients to develop skin breakdown or a pressure ulcer. This study addressed the following questions:

1. Which support surface or combination of surfaces would provide the lowest interface pressures under the bony prominences of the children?
2. Which support surface or combination of surfaces would be the most cost-effective for the children?

METHODS

Setting/design

This study was conducted in the General Clinical Research Center located within Texas Children's Hospital in Houston, Texas. Initially, the investigators had planned to conduct this study in the pediatric intensive care unit (PICU), but when they identified all of the different support surfaces and combinations of products that were currently used, it became apparent that an experimental design would not be feasible. A critically ill child could not be moved to several different support surfaces for testing purposes. This descriptive study was then developed as a pilot to assist the researchers in determining a sample size and selecting a few support surfaces with the lowest interface pressures for a future experimental study design. This study would assist WOC nurses and other health care practitioners in identifying an appropriate support surface that is therapeutic and cost-effective for the pediatric population.

Subjects

The researchers decided to do an initial pilot study using healthy children from the community who would represent a sample of children admitted to the hospital. Approval for the study was received from Baylor College of Medicine's Institutional Review Board. A random number of 50 subjects was selected, because no previous studies had been done that could be used for a power analysis. These healthy children would each be placed on all of the selected surfaces that were used in the pediatric intensive care unit. By analyzing the children on all of the surfaces, the investigators could determine if age or weight was pertinent in the performance of the surface and select the 2 best surfaces that provided the lowest interface pressures. These 2 surfaces could then be randomized in a future study in the PICU with critically ill children.

A convenience sample of healthy children between the ages of infant to 18 years was selected from the community. An advertisement for subjects was placed in the hospital newsletter. To ensure an equal distribution of ages within the total sample of children, 10 to 15 children were assigned to each of the following 5 age groups: infants to younger than 2 years; toddler/child (2 years to <6 years); child (6 years to <10 years), preteen (10 years to <14 years); and adolescent (14 to 18 years). This age distribution was derived from the study of data related to how body mass distribution changes with age.[20] The children were assigned to 30-minute time slots to allow enough time to move each child to 5 different surfaces or combination of surfaces and collect 3 interface pressure readings on each surface.

Instrument

To obtain the interface pressures, the Mini-TIPE was used (Tee-Kay Applied Technology, Stafford, Tex). The Mini-TIPE consists of a display unit, an interconnecting cable, and a 5.5-inch × 5.5-inch elastomeric sensor pad or a single pressure-sensing cell. The pad contains a matrix of 16 pneumatically activated switches, each of which is connected to a light-emitting diode in the display unit. The Mini-TIPE is operated with a 9-volt battery and is insulated, so there was no electrical shock hazard.

The technology for the interface pressure transducer used in this study was tested for validity and reliability when the instrument was first developed in the early 1970s.[21] In these experiments, tests were conducted to determine how accurately the transducer was accounted for the applied weight and how much variation there was in the readings when the test conditions were repeated at different points in time and with different operators. The results of the tests showed that the instrument was able to account for more than 97% of the load that was placed on it and that multiple readings taken under the same test conditions varied by ±3 mm Hg. In the worst test conditions, the readings varied by less than ±2 mm Hg. Under most test conditions, the tests demonstrated that the instrument could detect changes of 1 mm Hg. This sensitivity could cause repeat readings taken on living subjects to vary by up to 8 mm Hg because of changes in posture, wrinkles in the support surface covering, and shifts in the position of soft tissue that occur when a person moves. Thus, a series of 3 readings was taken with the transducer in the "same position," and then the transducer shifted and another series of readings was collected to ensure that the highest pressure was recorded. The highest reading was recorded as the interface pressure at that site.[21]

Procedure

On arrival at the Research Center, the children and their parents were met by a researcher who explained the study in detail and reviewed the consent. The parents were allowed time to read and sign the consent. Developmentally age-appropriate explanations of the study's purpose and how the interface pressure measurements were to be obtained were discussed and demonstrated for the children of appropriate age to obtain verbal assent. A few of the toddlers did not agree to participate in the study after the explanation and thus were not included. The children were then asked to change into hospital scrubs and remove their shoes and socks. Measurements of their height and weight were then obtained.

Each child was placed in a supine position for the measurements on a maximum of 5 support surfaces or surface combinations for approximately 3 to 5 minutes each while the interface pressure readings were obtained. The crib and standard mattress were the hospital mattresses routinely used at Texas Children's Hospital in Houston. The crib foam overlay and bed foam overlay were the Delta 120 2.75–inch crib, 3.5–inch bed by Span-America Medical Systems. The gel pillow was the Gel-E-Donut in infant or adult sizes by Children's Medical Ventures. The low-air-loss bed was the Efica by Hill-Rom, Batesville, Ind.

The support surface combinations included in this study were as follows:

- Set 1: Crib mattress
- Set 2: Crib mattress with 2.75-inch Delta foam overlay
- Set 3: Crib mattress with Gel-E-Donut pillow
- Set 4: Crib mattress with 2.75-inch Delta foam overlay and Gel-E-Donut pillow
- Set 5: Efica low-air-loss bed
- Set 6: Standard mattress
- Set 7: Standard mattress with 3.5-inch Delta foam overlay
- Set 8: Standard mattress with Gel-E-Donut pillow
- Set 9: Standard mattress with 3.5-inch Delta foam overlay and Gel-E-Donut pillow

The 5 age groups were each evaluated on 5 surface set combinations:

Measuring occiput site only:

- 0 to <2 years: Evaluated on sets 1-5 (using infant-size Gel-E-Donut)
- 2 to <6 years: Evaluated on sets 5-9 (using adult-size Gel-E-Donut)

Measuring occiput, coccyx, and heel sites:

- 6 to <10 years: Evaluated on sets 5-9 (using adult-size Gel-E-Donut)
- 10 to <14 years: Evaluated on sets 5-9 (using adult-size Gel-E-Donut)
- 14 to 18 years: Evaluated on sets 5-9 (using adult-size Gel-E-Donut)

One person trained to use the Mini-TIPE placed the sensors under the child's occiput, coccyx, and heel (depending on age group) to obtain a reading. The second person recorded the reading on a data collection log. The sensors were disinfected between uses with a hospital-approved cleaner (eg, isopropyl alcohol). A Child Life Specialist was enlisted to assist with distraction and entertainment for the younger children during the measurements. On days that the Child Life Specialist could not be present, a box was provided with toys and bubbles for the researchers to use to keep the smaller children occupied and assist them in remaining still for the measurements.

Data Analysis

The Mini-TIPE instrument provided readings to the tenth decimal; however, the recorded interface pressure scores were rounded to the nearest whole number. If the Mini-TIPE provided a reading of >100 mm Hg, which was common when measuring the peripheral heel, a 100 score was used in the analysis. If a reading of <10 mm Hg was obtained, which was common when measuring under the coccyx, a score of 10 was used in the analysis. The

Table 1. Patient characteristics (N = 54)

Age group	No. in group	Mean age ± SD (y)	Mean weight ± SD (kg)	Mean height ± SD (cm)
0-<2 y	13	9.9 mo ± 5.6	9.2 ± 2.3	72.5 ± 10.3
2-<6 y	8	3.4 ± 0.9	16.1 ± 2.5	100.2 ± 7.3
6-<10 y	16	7.8 ± 1.5	30.9 ± 11.6	130.2 ± 10.4
10-<14 y	10	11.7 ± 1.2	49.6 ± 10.4	157.3 ± 7.5
14–18 y	7	14.7 ± 1.0	69.7 ± 19.4	169 ± 9.9

Table 2. Infant (0-<2 y) occipital pressures of 5 bed surfaces (N = 13)

Surface	Mean ± SD (mm Hg)	Range (mm Hg)
Standard crib mattress	61 ± 19	36-91
Delta foam overlay	26 ± 6	15-34
Gel-E-Donut pillow	32 ± 10	22-58
Delta foam overlay + Gel-E-Donut pillow	26 ± 9	13-44
Efica low-air-loss bed	32 ± 13	13-59

data measurements were analyzed with the analysis of variance (ANOVA) method for repeated measures (Analysis of Variance and Covariance with Repeated Measures, BMDP Statistical Software, Inc., Los Angeles, Calif) to determine if one or more interface pressure differences between the surface types were statistically significant. If significance was revealed by ANOVA, paired *t* tests between all the support surface types were performed to identify which specific differences were significant. A Bonferroni adjustment was made to accommodate for the multiple comparisons of the 5 different surface types for each subject. The *P* value of each post hoc comparison was multiplied by the number of comparisons. Thus, for 5 support surface comparisons for each subject, the *P* value was multiplied by five.[22]

RESULTS

Description of Sample

The children in this study were recruited from the community as healthy volunteers. The children were categorized by age into 5 groups: infants to <2 years, 2 to 6 years, 6 to 10 years, 10 to <14 years, and 14 to 18 years. The total sample size consisted of 54 children: 24 girls and 30 boys. Their ages ranged from 3 months to 16 years. Their weight ranged from 6.43 kg to 98.1 kg, and their height ranged from 59.5 cm to 185 cm (see Table 1). The actual time it took for each child was approximately 15 to 20 minutes. The infants and toddlers took the most time because of the need for more explanations and distraction methods to keep them still for the pressure readings.

The first research question focused on the support surfaces that provided the lowest interface pressures under the bony prominences of children. The children in each age group were placed on 5 support surface combinations and interface pressures were measured. If the children were younger than 6 years of age, only the occipital interface pressures were measured because this is the largest surface area of their body and the most at-risk area for pressure mass.[20] For children 6 years and older, interface pressure measurements were taken under their occiput, coccyx, and heel.

Comparison of 5 Support Surfaces: Occipital Interface Pressures (Infants to <2 Years of Age)

- Surface 1: Crib mattress
- Surface 2: Crib mattress + 2.75-inch Delta foam overlay
- Surface 3: Crib mattress + Gel-E-Donut pillow (infant size)
- Surface 4: Crib mattress + Delta foam overlay + Gel-E-Donut pillow
- Surface 5: Efica low-air-loss bed

Results of the repeated measures ANOVA revealed significant pressure differences, [F (4,2809.7) = 24.8; $P < .001$] between one or more groups. The *t* tests for pair-wise differences revealed that all 4 modified surface types had significantly lower pressures than did the crib mattress ($P < .001$). The Delta foam overlay produced a lower pressure under the occipital area than did the Gel-E-Donut pillow (t [df 12] = 2.73; $P = .018$) and the Efica (t [df 12] = 2.08; $P = .059$). A similar difference was also found in the Delta foam + Gel-E-Donut group rather than the Gel-E-Donut by itself (t [df 12] = 1.95; $P = .075$).

The mean pressures did not differ between the 2 surfaces with the lowest pressures (Delta foam and Delta foam + Gel-E-Donut, t [df 12] = 0.21; $P = .834$). Individual subject level differences between these 2 surfaces showed a range of 16 units in either direction (see Table 2).

Table 3. Occipital pressures of 5 bed surfaces for children 2-16 y (N = 41)

Surface	Mean ± SD (mm Hg)	Range (mm Hg)
Standard bed mattress	53 ± 27	0 ± 100
Delta foam overlay	28 ± 14	0 ± 58
Gel-E-Donut pillow	24 ± 10	0 ± 39
Delta foam overlay + Gel-E-Donut pillow	26 ± 12	0 ± 55
Efica low-air-loss bed	32 ± 17	0 ± 68

Table 4. Coccyx pressure of 3 bed surfaces for children 6-16 y (N = 33)

Surface	Mean ± SD (mm Hg)	Range (mm Hg)
Standard bed mattress	8 ± 9	0 ± 30
Delta foam overlay	6 ± 8	0 ± 30
Efica low-air-loss bed	5 ± 7	0 ± 28

Table 5. Peripheral heel pressure of 3 bed surfaces for children 6-16 y (N = 33)

Surface	Mean ± SD (mm Hg)	Range (mm Hg)
Standard bed mattress	81 ± 22	18 ± 100
Delta foam overlay	71 ± 17	37 ± 100
Efica low-air-loss bed	66 ± 20	26 ± 100

Comparison of 5 Support Surfaces: Occipital Interface Pressures (Children 2-16 Years of Age)

- Surface 1: Standard mattress
- Surface 2: Standard mattress + 3.5-inch Delta foam overlay
- Surface 3: Standard mattress + Gel-E-Donut pillow (adult size)
- Surface 4: Standard mattress + Delta foam + Gel-E-Donut pillow
- Surface 5: Efica low-air-loss bed

In this analysis, the participants were grouped into the 4 age categories to test if surface pressure might also be affected by age, and therefore weight or size. Age had no effect on pressure, nor was an interaction between age and surface type found. Significant surface type differences were revealed, and all pair-wise comparisons were performed as indicated previously.

As with younger participants, all surface types showed significantly lower pressures than the standard mattress [F (4,5061.9) = 26.3; P = .000]. In addition, the Gel-E-Donut by itself or with the Delta foam overlay had significantly lower occipital pressures than did the Efica bed (t [df 40] = 2.62; P = .012 and t [df 40] = 2.23; P = .032, respectively). The Delta foam overlay showed a difference of 4 mm Hg from the Efica bed (t [df 40] = 1.80; P = .78). There were no detectable differences among the Delta foam overlay, Gel-E-Donut, and Delta foam overlay + Gel-E-Donut (see Table 3).

Comparison of 3 Support Surfaces: Coccyx and Heel Interface Pressures (Children 6-16 Years of Age)

- Surface 1: Standard mattress
- Surface 2: Standard mattress + 3.5-inch Delta foam overlay
- Surface 3: Standard mattress + Gel-E-Donut pillow (adult size)
- Surface 4: Standard mattress + Delta foam overlay + Gel-E-Donut pillow
- Surface 5: Efica low-air-loss bed

Coccyx pressures on 3 support surfaces (Efica, standard mattress, and Delta foam overlay) were measured on 33 participants between the ages of 6 and 16 years. Repeated measures ANOVA did not reveal any significant differences between these surfaces [F (2,50.19) = 1.89; P = .159] (see Table 4).

Perpendicular heel interface pressure measurements showed significant differences between the surfaces [F (2,2062.8) = 6.43; P = .003]. Pair-wise comparisons demonstrated a significantly lower pressure in the Efica bed and Delta foam overlay groups than with the standard mattress (t [df 32] = 3.38; P = .002 and t [df 32] = 2.60; P = .014). The Efica–Delta foam difference was not significant (see Table 5).

Oblique lateral heel pressure measurements were performed on only 20 of the subjects to compare them with the perpendicular heel measurements. The Delta foam overlay mean pressure is 16 mm lower than the standard mattress pressure, which is a significant difference (t [df 19] = 2.09; P < .05). The Delta foam overlay, on average, is 11 mm of pressure lower than the Efica bed, but the difference was not significant (t [df 19] = 1.14; P = .084). These analyses were done for the set of persons (n = 20) who had all 3 surfaces measured. A pair-wise deletion of cases was also performed, but there were no qualitative differences. The Delta foam overlay and the Efica bed were effective in providing similar low interface pressures under the heels (see Table 6).

The second research question assessed cost-effectiveness. Cost-effectiveness of support surface

Table 6. Oblique heel pressures of 3 surfaces for children 6-16 y (N = 20)

Paired samples statistics	Surface pairs	Mean ± SD (mm Hg)
Pair 1	Efica low-air-loss	46 ± 19
	Standard mattress	51 ± 25
Pair 2	Efica low-air-loss	46 ± 19
	Delta foam overlay	35 ± 20
Pair 3	Standard mattress	51 ± 25
	Delta foam overlay	35 ± 20

The time it took to take 3 pressure readings on each support surface varied, depending on the age of the subject.

therapies has been studied previously with adults and discussed in the literature.[9,10,18] To determine the cost-benefit ratio of the therapies used in this study, a brief cost-analysis of the various support surfaces was completed. For this example, 10 days was selected as the average length of time spent on a support surface. The prices represent the hospital's cost as of March 2002 at the investigators' institution, using 7 days as the time frame that represented the average length of stay in the PICU.

- Low-air-loss bed: $135/day × 7 days = $945 with scale
- Gel E donut (infant & adult): $7.50 one-time charge, replace pillow every 3 weeks per manufacturer recommendations
- Foam overlay: $46.08 one-time charge (crib size) $47.61 one-time charge (bed size)
- Gel E donut + foam overlay: $7.50 + $46.08 = $53.58 (crib size) $7.50 + $47.61 = $55.11 (bed size)

In the infant to <2-year-old group, the Delta foam overlay alone and with the Gel-E-Donut pillow achieved the lowest occipital interface pressure measurements but were not significantly lower than the Efica low-air-loss bed. Thus both therapies are effective, but the cost difference is a one-time charge of $46.08 for a crib size Delta foam overlay or $53.58 for the Delta foam overlay and Gel-E-Donut compared with $945 for the Efica bed. Based on this cost analysis and our research findings, it appears that the most cost-effective therapy for patients younger than 2 years of age would be the foam overlay.

In the 2- to 16-year-old group, the Delta foam overlay combined with the Gel-E-Donut pillow provided significantly lower pressures under the occipital area. The coccyx and heel interface pressures were similar when measured with the Delta foam overlay and the Efica low-air-loss bed. For children younger than 6 years who are most at risk for occipital breakdown because of their body proportions, a one-time charge for a Delta foam overlay plus a Gel-E-Donut pillow is $55.11 compared with $945 for an Efica bed. For older children, the cost comparison for the therapies evaluated in this study indicate that the one-time charge of $47.61 for the bed-size Delta foam overlay is more cost-efficient than the $945 charge for the Efica low-air-loss bed.

The cost analysis done here demonstrates the cost-effectiveness of the Delta foam overlay with and without the Gel-E-Donut. Based on our research, the Efica low-air-loss bed was the most costly therapy and did not demonstrate the ability to provide significantly lower interface pressures than the other therapies in this pediatric study sample.

DISCUSSION

This study was done to investigate several support surfaces used alone and in combination with one another to determine which surface produced the lowest interface pressures under the bony prominences of children and which surface was the most cost-effective. All surfaces studied provided significantly lower pressures than the standard hospital mattress, which were similar to results found in the adult studies.[3,6-9,11]

Children younger than 6 years had only the occipital interface pressure measurements taken because of the large surface area of their head, resulting in this area being most at risk for high pressures. In the infants <2 year group, the Delta foam overlay alone provided the lowest occipital pressures, and for children older than 2 years, the Delta foam overlay plus the Gel-E-Donut pillow provided significantly lower occipital pressures. The Efica low-air-loss bed can not be programmed for a weight less than 22.7 kg and is not recommended for children less than this weight by the manufacturer. When small children were placed on the Efica bed, their occipital area fell in the upper midsection of the mattress designed for pressure relief of the trunk of an adult. Thus, the pressures were not lower than the Delta foam overlay. The Gel-E-Donut pillow also did not demonstrate consistently low interface pressures in our critical age groups, who are at risk for occipital breakdown, when used alone. Therefore, the lowest occipital interface pressure measurements were found with the Delta foam overlay alone or in combination with the Gel-E-Donut pillow.

The children 6 to 16 years of age had 3 interface pressure measurements taken, which were under the occiput, coccyx, and heel, to evaluate the support surface. The highest interface pressure measurements that were obtained out of all 3 occurred when the heel was perpendicular to the support surface. These perpendicular heel pressures were significantly higher than at the occiput or the coccyx. The coccyx pressure was the lowest of all 3 pressures measured, which was probably the result of the normal curvature of the lumbar spine on the surface. Of note was that heel pressures were greatly reduced when the heel was repositioned

KEY POINTS

- The Delta foam overlay with and without the Gel-E-Donut pillow provided an effective pressure reducing surface for children, from infancy through 16 years of age.
- The Delta foam overlay performed similar to the Efica low-air-loss bed for providing pressure reduction under the coccyx and heel of older children.
- The Delta foam overlay and Gel-E-Donut pillow are very cost-effective modalities.
- The highest interface pressure measurements obtained in children 6 to 16 years of age were under the perpendicular heel. This pressure was greatly reduced when the heel was repositioned so the ankle was on its side in the oblique position.

with the ankle on its side in the oblique position. This is because of the greatly increased surface area that is available to support the weight of the foot when the heel is not perpendicular to the support surface. As in adults, the legs of these older children should be positioned to allow the ankle to rest on its side to protect the heel from pressure damage.

Although the Delta foam overlay plus the Gel-E-Donut pillow produced significantly lower interface pressures under the occipital area, this is not the location most at risk for skin breakdown and pressure ulcers in children 6 years and older. As school-age children mature, their body proportions are changing, resulting in high-risk pressure areas at the coccyx and heels.[21] The performance of the Efica low-air-loss bed and Delta foam overlay were similar but vary greatly in terms of cost. The Delta foam overlay is a one-time charge item that provided adequate pressure reduction for the coccyx and heels of these pediatric subjects.

Strengths

This study had a large sample size of 54 children with a good representation of age distribution. The convenience sample from the community portrayed children that were in good health and were of average make-up for weight and height comparisons. The sample size provided data results of significance up to $P < .001$.

All of the researchers using the Mini-TIPE for the interface pressure measurements were trained by one of the investigators (TAK) to decrease variability in the data collection. At the end of the training, repeated measures with the Mini-TIPE were within 5 mm Hg and interrater reliability readings were within 4 mm Hg. The interface pressures were measured under each bony prominence 3 times, and the highest score of the three was recorded. A qualified statistician then analyzed the data results using the repeated measures ANOVA for one or more groups and the t tests for pair-wise differences.

Limitations

The Efica HillRom low-air-loss bed has 5 zones to independently accommodate body weight and adjust to disperse pressure. The zones are head, chest, seat, thigh, and foot. When using the Efica low-air-loss bed, young children were routinely placed in the chest/seat section of the bed, as would have been done on the nursing unit. The young children fit within these 2 sections entirely and appear to be most comfortable and safe. If their head was placed in the head section, they appeared to be too high in the bed, especially if the head of the bed was raised. All of the Efica bed settings were the same for any child weighing less than 50 lb or less than 22.7 kg, because that was the design of the bed. The bed did not have individual zone adjustments for children weighing less than 50 lb. The zone adjustments were recorded for those children weighing more than 50 lb.

Variances from research protocol occurred in the infant to <2-year group, where 2 of 13 children were measured on the bed-size Delta foam overlay instead of the crib-size Delta foam overlay and 1 of 13 children had an adult-size Gel-E-Donut used when their occiput was measured. Also, 2 of the 8 children in the 2- to <6-year group had an infant-size Gel-E-Donut used when their occiput was measured.

There was variability in positioning the Gel-E-Donut pillow under the head of the subject because of neck position or hair thickness and in positioning the Mini-TIPE sensor under the bony prominences of the children. Children with very thick hair and braids had very low pressure scores, noted in 2 of the 16 children in the 6- to <10-year group and 1 of the 7 children in the 14- to 18-year group. The researchers attempted to decrease the variability of the positioning of the Mini-TIPE sensor by taking 3 readings under each prominence.

The time it took to take 3 pressure readings on each support surface varied, depending on the age of the subject. The estimated time of 3 to 5 minutes per measurement was generous if the child was co-

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More research is needed to identify which of these support surfaces provide the lowest interface pressures in a population of critically ill children and skin breakdown and/or pressure ulcer occurrence in these children over time when they are placed on each surface.

operative. The infants and toddlers had to remain with their head still for at least 30 to 60 seconds per surface. This was accomplished by using a variety of distraction methods, such as blowing bubbles, using pacifiers, and/or bottle feeding the babies. The infants and toddlers took 10 minutes or less to move to the 5 different surfaces and obtain the readings. It took longer to obtain the pressure readings for the older children because 3 measurements were obtained under 3 bony prominence sites. The average time for obtaining the readings in the older children was 15 to 20 minutes. There was also variability in interface pressures when the older children were lying too rigidly and not allowing their full weight to rest completely on the surface. Instruction was given to the children to relax completely while the measurements were taken.

It was also noted that in the clinical setting, the most common position of children in bed is the semi-fowler position, which would theoretically result in higher pressures in the coccyx area. The healthy children in this study were placed in a complete supine position, which resulted in a prominent sacral curve and very low pressure scores. These results were similar to those found in adult studies.[4,7,8]

SUGGESTIONS FOR FUTURE RESEARCH

This study helped identify a sample size for a future study with critically ill children in a PICU. In addition, the results narrowed the focus of the support surface combinations to the Efica low-air-loss bed, the Delta foam overlay, and the Delta foam overlay plus the Gel-E-Donut pillow. More research is needed to identify which of these support surfaces provide the lowest interface pressures in a population of critically ill children and skin breakdown and/or pressure ulcer occurrence in these children over time when they are placed on each surface.

SUMMARY

This study of healthy children ages 3 months to 16 years found that the Delta foam overlay produced the lowest interface pressures under the occipital area for children younger than 2 years. For children older than 2 years, the Delta foam overlay plus the Gel-E-Donut pillow produced significantly lower pressures under the occipital area and performed similar to the Efica low-air-loss bed for providing pressure reduction under the coccyx and heel. The Delta foam overlay alone or in combination with the Gel-E-Donut pillow is a very cost-effective and therapeutic choice for pressure reduction as demonstrated in this study of healthy children.

Acknowledgment

We offer special thanks to the General Clinical Research Center, the nursing staff at the General Clinical Research Center, Marilyn Hockenberry-Eaton, Viola Velaso, RN, Jean McCain, RN (Hill-Rom), Paul Daly (Children's Medical Ventures), Mark Krouskop, and Texas Children's Hospital for their assistance with and support of our study.

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