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Bed-exit alarm effectiveness

Elizabeth Capezuti[a,*], **Barbara L. Brush**[b], **Stephen Lane**[c], **Hannah U. Rabinowitz**[d], and **Michelle Secic**[e]

[a]University of Pennsylvania School of Nursing, Philadelphia, PA 19104, USA

[b]University of Michigan School of Nursing, 400 N. Ingalls, Room 3160A, Ann Arbor, MI 48109-0482, USA

[c]Amron Corporation, 1313 Dolley Madison Blvd., Suite 300, McLean, VA 22101, USA

[d]Aventura Hospital and Medical Center, Aventura, FL 33180, USA

[e]Secic Statistical Consulting, Inc. P.O. Box 745, Chardon, Ohio 44024, USA

Abstract

This study describes the accuracy of two types of bed-exit alarms to detect bed-exiting body movements: pressure-sensitive and a pressure sensitive combined with infrared beam detectors (dual sensor system). We also evaluated the occurrence of nuisance alarms, or alarms that are activated when a participant does not attempt to get out of bed. Fourteen nursing home residents were directly observed for a total of 256 nights or 1,636.5 hours; an average of 18.3 ± 22.3 (± S.D.) nights/participant for an average of 6.4 ± 1.2 hours/night. After adjusting for body movements via repeated measures, Poisson regression modeling, the least squares adjusted means show a marginally significant difference between the type of alarm groups on the number of true positives (mean/S.E.M. = 0.086/1.617) for pressure-sensitive vs. dual sensor alarm (0.593/1.238; p = 0.0599) indicating that the dual sensor alarm may have a higher number of true positives. While the dual sensor bed-exit alarm was more accurate than the pressure sensitive alarm in identifying bed-exiting body movements and reducing the incidence of false alarms, false alarms were not eliminated altogether. Alarms are not a substitute for staff; adequate staff availability is still necessary when residents need or wish to exit bed.

Keywords

nursing homes; bed-exit alarm; bed and mattresses; falls of elderly; physical restraint; side rail

1. Introduction

Most falls in nursing homes occur in the resident's room, especially during attempts to get in or out of bed (Agostini et al., 2001; Capezuti et al., 2002). Bed-exit alarms, designed to detect patient's movement out of bed, increase staff surveillance of cognitively and/or physically impaired residents at risk for bed-related falls. Whether directly attached to the resident as a

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*Corresponding author: Present address: Hartford Institute for Geriatric Nursing, New York University College of Nursing, 246 Greene Street, 6th Floor, New York, NY 10003-6677, USA. Phone: +(1-212)-998-5376, Fax: +(1-212)-477-4344, Email: ec65@nyu.edu.

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garment clip or position change alarm, or part of the bed itself (e.g., pressure-sensitive mats, bedside infrared beam detectors, or in-bed pressure sensors), bed-exit alarms inform staff by letting them know when a person is attempting to leave the bed, has gotten out of bed, or has fallen (Miskelly, 2001).

Despite the widespread usage of these devices and their endorsement by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) as valuable tools in fall prevention (JCAHO, 2000; Coles et al., 2005), the overall reliability of bed-exit alarms in detecting resident movements out of bed has not been well established (Agostini et al., 2001; Gillespie et al., 2003). A few clinical trials have been conducted to test alarm effectiveness in fall prevention, however, they either failed to reach statistical significance (Tideiksaar et al., 1993) or did not include a control group (Widder, 1985; Kelly et al., 2002). Although alarms have been part of clinical trials demonstrating the efficacy of multi-component fall prevention interventions, the evidence to support the individual contribution of alarms to fall reduction is not evident (Agostini et al., 2001; American Geriatrics Society, 2001; American Medical Directors Association, 2003; Oliver et al., 2007). Moreover, case reports described in the literature or reported to ECRI or the U.S. Food and Drug Administration (FDA) have indicated problems with false alarms as well as failure to alarm accurately (Anonymous, 1997, 2000, 2003, 2004a, 2004b; U.S. FDA, 2006).

As part of a larger study aimed at developing of a device to deter unassisted transfer, we examined the effectiveness of bed-exit alarms in detecting actions that could lead to a fall or injury. This study aims to describe the accuracy of two types of bed-exit alarms to detect bed-exiting body movements: pressure-sensitive and a pressure sensitive combined with infrared beam detectors (dual sensor system). We also evaluated the occurrence of nuisance alarms, or alarms that are activated when a participant does not attempt to get out of bed. Finally, we describe the how participants attempt to get out of bed.

2. Methods

2.1. Design

This is a secondary analysis of a Phase 2, NIH-funded Small Business Innovation Grant whose aim was to develop a commercial device to deter “escapes” from bed (DEB). The DEB device is placed on the side of a hospital bed to detect and then prevent a patient’s attempted egress from bed. It consists of two physical components: (1) a device to detect the attempted exit and play a voice message urging the older person to remain in bed; and (2) a large bag next to the patient’s bed, inflated by low pressure air, that provides a “soft” air-filled barrier at the edge of the bed. A supporting objective of this grant was to determine the precise mechanism by which older, confused persons get out of bed that would inform the design of the DEB device. In order to address both study objectives, a bed-exit alarm was used to identify the patient’s attempt to get out of bed that would signal the voice message to play and the air bag to inflate as promptly as possible. Testing of the effectiveness of the DEB devise and the bed-exit alarm was conducted in the nursing home resident’s bed, recorded by video camera, and directly watched by a trained bedside observer.

2.2. Site and participants

The study was conducted in a 120-bed, non-profit, non religiously-affiliated nursing home in Philadelphia. The nurse manager of each 60-bed unit identified all residents (n = 22) who fulfilled the following criteria: (1) cognitively impaired, (2) had difficulty with either transfer out of bed or walking safely, and (3) was perceived by the nursing staff to be at high risk for a bed-related fall. Sixteen nursing home residents (or their proxies) agreed to participate. Of the 16 consented participants, the video data was unusable for two participants because the

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video equipment did not record properly. The informed written consent and study procedures were approved by the University of Pennsylvania Institutional Review Board and the Pennsylvania Department of Health.

2.3. Study procedures

Twelve bedside observers were recruited and trained by the project manager, a registered nurse. Training included instruction on how to set up the video equipment, document participant movements, and implement safety precautions, including when to call the nursing home staff for assistance. Each observer signed a statement attesting to an understanding of the procedures necessary to maintain the confidentiality of the videotape and data sources. In addition to demonstrating competency in equipment setup, the observers were asked to describe their response to several potentially difficult clinical issues, such as when a participant becomes physically or verbally abusive. The project manager directly observed each observer's performance of on-site video recording with consented participants, for at least two nights or until the observer demonstrated 100% agreement with the manager for appropriate response to participant's bed movements, and documentation of alarm activation and reliable execution of their responsibilities. The project manager reviewed the tapes prior to sending them to the investigators in order to check the quality of the recordings and the accuracy of the observer's documentation. The observers' reactions to challenging participant situations were evaluated and the project manager provided feedback and reinstruction, as needed, to ensure empathic and competent performance by all observers.

The in-bed data collection occurred in the participant's usual bed and room in the nursing home. The bedside observer set up the video equipment before the resident's usual hour of sleep (usually about 9 pm) and verified that the alarm system was functioning properly. The latter included checking sensor integrity, insuring that connections between the parts were secure, and that the control unit and indicator bulb responded to pressure/position changes. The equipment was removed before the resident awakened (about 5 am). Tapes were placed in the locked cabinet of the audiovisual (AV) cart used to hold the equipment which was subsequently stored in a locked closet in the nursing director's office. The number of nights of video recording was based on the data obtained from each participant. Since our goal was to observe participant body movements in bed, the number of nights varied considerably among the participants since some moved frequently and others moved only occasionally.

The bedside observer was positioned to effectively observe the participants' sagittal and frontal plane movements in order to evaluate bed-exit alarm effectiveness. The bedside observer was also present as a precautionary measure to ensure that if any participants attempted to exit bed, they did not fall and sustain injury. Other safety precautions implemented to reduce the risk of injury included positioning the bed in its lowest position and placing a bedside mat next to the bed. Since all participants were right handed and their right side was stronger than their left, all participants entered and exited their beds from the right side. Thus, the bedside observer sat in a chair positioned within 2 feet of the lower right side of the bed. A full side rail was raised on the left side. The observer intervened if the participant's lower extremities contacted the floor or if more than 25% (i.e., one upper or lower extremity) of the participant's body leaned over the edge of the bed. In these cases, the bedside observer was instructed to assist the participant back in bed as needed or to contact the appropriate nursing staff to assist the participant to the bathroom.

Initially, the alarm device was used to detect bed egress. It included two pressure-sensitive strips, approximately 3 inches wide, placed under the fitted bed sheet at the level of the resident's buttocks and shoulders that activated the alarm once the resident lifted either body part off the sensor pad. A two strip system was used since it is considered optimal for restless patients with dementia that may display a high degree of upper or lower body activity

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(Anonymous, 2004a), however, there were several undetected attempts to leave the bed and several false alarms. The "strips," were replaced with extra-wide pads commonly used for chair alarms (Anonymous, 2004a). Although we attempted various configurations (e.g., at the side of the resident) of the strips and the pads on the participant's bed, there continued to be problems with the sensor detecting bed-exiting movements. These strips and pads were replaced with a pressure mat, approximately a third of the mattress length, that was placed under the mattress in the bottom third of the bed (Miskelly, 2001).

A second alarm system, developed by the primary study's principal investigator (author, SL), employed both bed pressure sensors and an array of five infrared beam transmitter receivers with associated reflectors that were placed in a horizontal line about 2 feet above the head of the bed. A narrow pressure sensitive pad was then placed along the open edge of the bed. These detectors were electrically connected to activate the alarm when both the infrared beam was broken and when there was weight on the edge of the bed over the sensor.

Participants were videotaped while they slept, thus, recording began after the participant was in the bed (usually about 10 pm) and ended prior to awakening (usually about 5 am). The VHS video camera was placed 2 feet from the bottom end and 1 foot above the perpendicular plane of the participant's bed. For videotaping, a black and white video camera with low light level and high resolution was used. The camera and a low light source were mounted on a tripod with 110 volt power that was attached to an AV cart. A nine-inch back and white video monitor, placed on top of the AV cart, faced the bedside observer to ensure that the camera was working and recording the camera input via a high resolution, real/lapse time video recorder with time/date stamp.

The alarm informer control box was placed on the headboard or bedside table. When the alarm sensors or sensor/infrared beam were activated, it triggered a dim light; the alarm did not sound to avoid wakening or disturbing the participant. The 8-hr capacity of VHS format tapes ran full time in order to capture as many details of pre-and post- exiting behaviors as possible. Existing light levels in the room were adequate to produce clearly visible images and the light that was activated during exit attempts further enhanced the details of the recording. To improve the quality of the video recordings, we used an automatic focus camera and reduced flicker by recording over all tapes with the lens cover on before rewinding and recording data (Roberts et al., 1996).

2.4. Measures

2.4.1. Baseline clinical characteristics—Prior to the intervention, the project manager, a registered nurse (HUR), conducted a comprehensive physical assessment of each participant, noting their dominant handiness and determining any one-sided muscle strength weakness or immobility. Demographic and falls data were collected from medical records. Falls data were obtained from a review of nursing home incident reports in the year preceding the baseline evaluation. Since the time of day and location for each fall was recorded, we were able to categorize the falls data as bed-related if occurring between 10 pm and 6 am in the bedroom. Other resident characteristics were obtained by resident and staff interviews using standardized instruments. Functional status was quantified with the physical function subscale of the Psychogeriatric Dependency Rating Scale (Wilkinson and Graham-White, 1980); scores range from 0–39 and higher scores indicate poorer function. Mobility assesses bed mobility, transfer ability and ambulation with scores ranging from 1 to 25 with higher scores indicating reduced mobility (Capezuti et al., 2007). Fall risk was evaluated with the Morse Fall Scale (Morse, 1997); total scores range from 1 to 125 with scores greater than 44 indicating a high risk for falls. Falls represent all reported falls for the one year period preceding baseline. Night falls are all reported falls occurring between 10pm and 6 am in the bedroom for the one year period preceding baseline. Cognition is measured with the Mini-Mental State Examination (MMSE;

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Folstein et al., 1975). Scores range from 0–30 with lower scores indicating poorer cognitive function; Cognitive impairment is defined as a score less than 24 on the MMSE. Behavioral symptoms were measured with the Nursing Home Behavior Problem Scale (Ray et al., 1992). Scores range from 0 to 116 with higher scores representing a greater number of behavioral symptoms.

2.4.2. In-bed body movement activity and alarm data—Although the video tape served as the primary data source, the bedside observer maintained a detailed log for each night of participation. This included: time, alarm type (bed sensor versus bed sensor and infa-red beam), resident consciousness level (awake or asleep), presence of leg movements while asleep, alarm informer status (positive or negative), position changes (i.e., moved entire body from prone to side), other body movements (i.e., lifted extremities), and any bed-exiting body movements. The latter meant that the participant either sat up and swung his/her legs off the bed or leaned more than 25% of his/her body onto or over the edge of the bed. If any of the body movements resulted in a limb, head, or other section of the body within the rails of a side rail or between the side rail and head/foot board, the movement was then categorized as a potential side rail entrapment body movement. The bedside observer recorded her findings at least every 30 minutes or when there was a change in body movements or position.

The principal investigator of the primary study (SL) and a research assistant (RA) reviewed the video tapes using the same variables recorded by the bedside observers in their logs. All video recordings of alarm informer events were also evaluated by the co-principal investigator (EC) to ensure accuracy of the research assistants' judgments concerning bed-exiting body movements.

The analysis of the video tapes focused on the qualitative description of the participants' attempts to exit bed, the quantification of bed-exiting body movements (number of exit body movements = NEXTIM) and determination of the accuracy of the alarm. Alarm accuracy was categorized as true positive, true negative, false positive, or false negative. A "positive" alarm was defined as when the alarm was activated (a small bulb lit next to the headboard) while a "negative" alarm indicated that the alarm did not activate. If the alarm activated during a bed-exiting body movement, the event was categorized as a "true positive", while an alarm activation when the participant did not move or the body movement (e.g., rolling over onto one's side from a prone position or shaking ones' arms or legs) did not represent a bed-exiting movement was considered a "false positive". When the alarm failed to activate during a true bed-exiting body movement it was defined as a "false negative". Subsequently, a "true negative" defined lack of alarm activation when the participant moved but did not display any bed-exiting body movement. After all data was entered into an SPSS (Statistical Package for the Social Sciences, SPSS Inc., Chicago) file using only the participant's study number, the videotapes were destroyed.

2.4.5. Statistical methods—The effect of the type of alarm on the true positives and true negatives was assessed. The number of true positives and true negatives were summarized by group (bed sensor vs. dual sensor, i.e., bed sensor + IR beam) with means, standard deviations, minimums, medians and maximums, as were the number of body movements (exit and non-exit), sensitivity and specificity. Repeated measures Poisson regression modeling was used to compare the groups on the number of true positives and number of true negatives, separately. The models were adjusted for the number of body movements (exit movements for true positive model and non-exit movements for true negative model). The modeling accounts for the fact that patients had multiple nights of data and could have experienced both types of alarms. P-values less than or equal to 0.05 we considered statistically significant.

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3. Results

3.1. Demographic characteristics

Characteristics of the fourteen nursing home resident participants (Table 1) represent a very physically and cognitively impaired group with a high number of behavioral symptoms. All participants received some type of psychoactive medication in the evening (antipsychotic, antidepressant, and/or hypnotic). Both fall risk scores and number of actual falls/night falls were high.

3.2. Body movements

Participants were directly observed for a total of 256 nights or 1,636.5 hours; an average of 18.3 ± 22.3, range = 4–83) nights/participant for an average of 6.4 ± 1.2; range = 1.5–9) hours/night. Participants demonstrated an average of 16.8 ± 7.7; range = 4–55) body movements that were not categorized as "bed-exiting." These included the following movements/behaviors: awake a mean of 3.9 ± 3.0 times per night (range = 0–23), moved legs while asleep an average of 3.4 ± 3.2 times per night (range = 0–24), changed position a mean of 5.2 ± 3.7 times per night (range = 0–26), moved their extremities within the rails of the side rail an average of 0.09 ± 0.4 times per night (range 0–3).

Bed-exiting body movements occurred, on average, 1.15 ± 2.5 times/night (range 0–20). These movements did not all demonstrate "typical" bed rise performance, i.e., sitting up and swinging legs off bed in one synchronous, quick movement (Alexander et al., 1992). Some demonstrated significant bed rise difficulty and took much longer than those who rose in a synchronous trunk-legs movement. A few participants elevated their trunk by pushing off the bed with their arms several times prior to moving their legs over the side of the bed. A third variant was those that leaned or rolled their trunk onto the bed's edge and then the legs slid off the side of the bed with the trunk and head following.

3.3. Alarm outcomes

Four patients had bed sensor only, 7 patients had bed sensor + IR beam only, and 3 patients had both bed sensor and bed sensor + IR beam on various nights of stay. Table 2 shows descriptive statistics for the endpoints of interest. First, the assessment of the true positives was summarized using the number of true positives (NTP), the number of exit body movements (NEXITM) and the sensitivity. Second, the assessment of the true negatives was summarized using the number of true negatives (NTN), the number of non-exit body movements (NBODYM) and the specificity. Table 3 shows results from the modeling of the true positives (NTP) and true negatives (NTN). Because patients had a variety of body movements, nights studied, and type(s) of alarms, the modeling accounts for these factors. Body movements and nights studied were highly correlated, thus only one was necessary in the final model. The final model also produces means of the endpoints that are adjusted for the covariates in the model. After adjusting for body movements (number of exit body movements or NEBM and number of non-exit body movements or NNEBM) via repeated measures Poisson regression modeling, the least squares adjusted means (LSM) show a marginally significant difference between the type of alarm groups on the number of true positives (mean/SEM = 0.086/1.617) for pressure-sensitive vs. dual sensor alarm (0.593/1.238; $p = 0.0599$) indicating that the dual sensor alarms have a higher number of true positives than the pressure-sensitive alarms.

4. Discussion

This analysis of the effectiveness of dual sensor and pressure sensitive bed-exit alarms revealed several findings that have important clinical ramifications for bed fall risk and prevention. First, we found that the study participants exited bed in three distinct ways that may influence how

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well bed-exit alarms function. This variability in bed egress supports the need for supplemental measures to assist alarms in detecting when residents are attempting to exit their beds and provide safety alternatives for fall prevention. For example, with individuals who primarily use their upper extremities to pull themselves up before lowering their feet and legs to the floor, equipment such as bed grab bars and bed handles attached to the bed frame or mattress might prove useful (Alexander et al., 1992, 2000). Since it is more difficult to rise from a highly compressible mattress, a firm mattress or a folding bed board placed under mattress can also facilitate bed mobility and standing (Capezuti et al., 1999).

Residents who lean toward the edge of the bed prior to dropping their legs over the side may benefit from lowered siderails, since this seems to be the bed egress most commonly associated with fatal side rail entrapment (Miles and Parker, 1998). Indeed, our study findings suggest that this latter type of egress is not uncommon. In Miles and Parker's (1998) case analysis, one of the victims wore a garment clip alarm. Unfortunately, the cord failed to detach from the control box which would have triggered the alarm and the resident asphyxiated. Most disturbing was our finding of 15 incidents, representing 7 participants, who were observed with their arms or legs within the side rails. Considering the lack of evidence supporting the use of side rails (Capezuti et al., 2002, 2007; Oliver, 2002) in bed-related fall prevention and their potential fatal consequences (JCAHO, 2002), use of these devices should be limited to in-bed and transfer enablers but may require modification to reduce entrapment risk (Powell-Cope et al., 2005).

Because our study tested alarms on "real" nursing home residents rather than hypothetical cases, we also demonstrated that type of egress must be coupled with knowledge about patient size and patient body movements to most accurately identify bed-exiting. Careful video observation data was used to optimize the sensor/alarm configuration, including the addition of infrared beam detectors, and settings to promote the timely activation of the alarm. Thus, we refute the "one size fits all" approach to bed alarm use and underscore the need for an individualized assessment of each resident when considering which alarm and supplements are needed to best elicit bed-exiting movements. This study has a small sample size, however, even with low power there was marginal statistical significance indicating that the bed sensor + IR beam may have a higher number of true positives than the bed sensor alone. This study is limited since the primary study, from which the data was obtained, was designed to develop a commercial device to deter "escapes" from bed. Thus, the findings presented warrants further research with a larger, more controlled study in a representative nursing home population.

Finally, while the dual sensor (pressure sensitive plus infrared beam detectors) bed-exit alarm was more accurate than the pressure sensitive alarm in identifying bed-exiting body movements and reducing the incidence of false alarms, false alarms were not eliminated altogether. One of the reasons for this, and a limitation of our study, was that we only tested one type and brand of sensor pad and alarm. A more comprehensive study of 16 alarm products from seven supplies by ECRI found wide variations in performance among the various products tested (Anonymous, 2004b). It also noted that bed-exit alarms function unreliably with low weight (less than 100 pounds) residents or among residents who are restless (Anonymous, 2004b). This is important considering that many nursing home residents at risk for falling have dementia which is often associated with underweight status (Cronin-Stubbs et al., 1997) and behavioral symptoms such as restlessness. Potential methods to enhance the effectiveness of pressure-sensitive alarms include: (1) individualization of delay time, (2) use of highly sensitive sensors to adjust for low weight, and (3) supplementing the pressure-sensitive alarm with other types of alarms that attach to the resident or their clothes (Anonymous, 2004a; 2004b). The latter include alarms that contain weight-bearing sensors placed on the thigh (Kelly et al., 2002) or position-sensitive sensors located behind the ear (Lindemann et al., 2005) or chest (Miskelly, 2001).

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The study participants, cognitively impaired older residents with poor safety judgment and a history of falls, are most likely to benefit from bed-exit alarms. Nursing home residents, however, can respond negatively to an audible alarm, i.e., become agitated or attempt to move away from the noxious sound. To reduce this problem, alarms should sound at a nurses' station or via a beeper-type device carried by the nurse. This can also reduce overall nighttime noise in the nursing home that can contribute to disturbed sleep (Schnelle et al., 1998).

Alarms, at approximately $150 to $300 per resident, are a major financial investment for facilities. Although no alarm is guaranteed to work reliability all the time, user recommendations for implementation and maintenance of alarms are available that enhance device functioning (Anonymous, 2004a, 2004b). The alarm type selected must consider the individual resident's style of egress, size, and related movement patterns (Anonymous, 2004a, 2004b). Tailoring the alarm type to these resident characteristics can improve alarm performance and ultimately reduce the risk of falls and related injuries. Alarms, however, are not a substitute for staff; adequate staff availability is still necessary when residents need or wish to exit bed (Capezuti et al., 1999). A bed-exit alarm is only one intervention within a comprehensive, multi-component fall prevention program that addresses the resident's unique needs.

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Table 1

Participant characteristics

Variables	Mean ± S.D.	Range
Demographic parameters:		
Age (year)	80.4 ± 5.9	71–93
African-American (%)	50.0	---
Female (%)	42.9	---
Length of stay (months)	23.43 ± 16.61	12–72
Physical health parameters:		
Functional status	26.21 ± 6.44	13–37
Mobility	11.14 ± 3.82	7–18
Fall risk	77.14 ± 10.14	60–90
Falls (in the last year)	4.57 ± 2.56	2–11
Night (10 pm -6 am) falls (in the last year)	0.86 ± 1.23	0–4
Mental health parameters:		
Cognition	5.14 ± 5.89	0–16
Behavioral symptoms	15.57 ± 9.29	0–32

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Table 2

Descriptive statistics for alarm outcomes

Endpoints	Type of alarm	n	Mean ± S.D.	Min	Median	Max
NTP						
	bed sensor (BS)	75	0.08 ± 0.319	0	0	2
	BS + IR beam	181	1.01 ± 2.461	0	0	20
NEXITM						
	BS	75	0.65 ± 1.121	0	0	6
	BS + IR beam	181	1.36 ± 2.806	0	0	20
Sensitivity						
	BS	26	0.11 ± 0.286	0	0	1
	BS + IR beam	67	0.71 ± 0.415	0	1	1
NTN						
	BS	75	0.01 ± 0.115	0	0	1
	BS + IR beam	181	0.08 ± 0.387	0	0	3
NBODYM						
	BS	75	17.67 ± 9.424	4	16	55
	BS + IR beam	181	16.48 ± 6.789	5	15	53
Specificity						
	BS	75	0.0008 ± 0.0072	0	0	0.06
	BS + IR beam	181	0.003 ± 0.017	0	0	0.14

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Table 3

Repeated measures Poisson regression modeling

Endpoint	Factor	Test stat.	p =	LSM of endpoint, SEM	
				BS	BS + IR beam
NTP	Type	3.54	0.0599	0.086, 1.617	0.593, 1.238
	NEBM	2.44	0.1181		
NTN	Type	1.59	0.2068	0.008, 2.846	0.064, 1.459
	NNEBM	2.34	0.1257		