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Exposure to inclined trunk postures in surgical staff

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ABSTRACT

In surgical staff, low-back pain (LBP) is prevalent and prolonged trunk inclination is hypothesized to be one of its potential causes. The aim of this study was to evaluate the magnitude and duration of trunk inclination in the sagittal plane of surgical assistants during surgical procedures. The three-dimensional trunk orientation was measured in 91 surgical assistants across four medical facilities during surgical procedures using an inertial measurement unit on the thorax. Per participant, Exposure Variation Analysis was used to evaluate the percentage of the total time of trunk inclination (< -10° (backward inclination); -10–10° (upright posture); 10–20° (light inclination); 20–30° (moderate inclination); >30° (strong inclination)) taking into account posture duration (< 10 s; 10–60 s; 60–300 s; > 300 s). Participants reported their LBP history and perceived low-back load during the procedure via a questionnaire. Participants were in an upright posture for 75% [63–84%] (median [interquartile range]) of the total surgery time (average surgery time: 174 min). Trunk inclination was beyond 20° and 30° for 4.3% [2.1–8.7%] and 1.5% [0.5–3.2%] of the surgery time, respectively. In most of the participants, the duration of trunk inclination beyond 20° or 30° was less than 60 s. Questionnaire response rate was 81%. Persistent or repeated LBP was reported by 49% of respondents, and was unrelated to the exposure to inclined trunk postures. It is concluded that other factors than prolonged trunk inclination, for instance handling of loads or prolonged standing may be causally related to the reported LBP in the investigated population.

1. Introduction

Surgical staff, including surgeons and instrumentation nurses or in some countries specifically trained surgical assistants, commonly report low-back pain (LBP). In one study 35% of the responding surgeons reported to experience LBP during surgery (Janki et al., 2017). Other studies reported 12-months prevalence among surgical staff ranging from 50% to even 70% (Epstein et al., 2018; Meijsen & Knibbe, 2007; Szeto et al., 2009) and a systematic review concluded that as many as 20 % of surgeons had lumbar degenerative disease (Epstein et al., 2018).

LBP was aggravated by daily work according to most surgeons with LBP (Szeto et al., 2009) and surgeons also self-reported a significant increase in LBP during or after surgery, where duration of the procedure significantly affected experienced pain. Both surgeons and surgical assistants associated their LBP with non-neutral postures during surgery (Meijsen & Knibbe, 2007; Szeto et al., 2009) and sustaining static or awkward postures during surgery was identified as the most prominent factor related to body discomfort by 90% of surgeons (Szeto et al., 2009). The causal role of non-neutral trunk postures in the development of LBP that the respondents in these studies appear to assume, is in line with the finding that exposure to such postures is consistently associated with LBP, as has been reported in several systematic reviews and meta-analyses (Griffith et al., 2012; Hoogendoorn et al., 1999; Swain et al., 2020).

Cumulative mechanical loading on the low back may explain an association between inclined (in frontal or sagittal plane) trunk postures and LBP (Coenen et al., 2014). Following this rationale, external supports to counteract the moments caused by the force of gravity on the inclined trunk have been proposed and tested as potential measures to prevent LBP in surgical staff (Albayrak et al., 2007; Marquetand et al., 2021). While these supports can unload the trunk, a more versatile solution may be the use of a trunk-support exoskeleton, as this would allow the user to move more freely (de Looze et al., 2016). However, these solutions assume that support against gravity is the best approach towards prevention. This may be in line with subjective self-reports on surgery work, but self-report is rather non-specific, often unreliable and may overestimate or underestimate specific exposures (Barrero et al., 2009; Burdorf & Laan, 1991; Van der Beek et al., 1994; Wiktorin et al.,

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1993). Therefore, more insight in the demands of the work in the operating room, based on objective measurements, is needed to select prevention approaches.

Inertial measurement units (IMUs) allow for objective assessment of trunk postures (Brouwer et al., 2020; Faber et al., 2009). These sensors are small and unobtrusive and can thus be used during surgery. One study, using IMUs, reported that surgeons spend 30% of the time during surgery in more than 20 degrees inclined trunk postures, which was classified as a high risk posture, but with a standard deviation of 22% (Meltzer et al., 2020). Another study (Yang et al., 2021), also on surgeons, reported a similar percentage of 35% [21–50%] (median [interquartile range]) in such postures for open surgery and a significantly lower percentage of 15% [8–25%] for laparoscopic surgery. Median trunk inclination angles were 17° [14–22°] versus 13° [10–17°]. Note that for all these outcomes variance between subjects was high, implying that exposure to inclined postures can be quite different between individual surgical assistants.

None of these studies included surgical assistants or instrumentation nurses. In addition, none of these reported to what extent inclined trunk postures were sustained for longer periods. Obviously, the duration that a posture is sustained without interruption co-determines the physiological and mechanical effects of a certain intensity of exposure (e.g., inclination angle) and likely the probability that a certain intensity of exposure can cause LBP (Courville et al., 2005; LaBry et al., 2004). Therefore, the current study was designed to objectively measure exposure to inclined postures in the sagittal plane with IMUs among surgical assistants during surgery work and to describe the exposure using Exposure Variation Analysis (EVA) (Mathiassen & Winkel, 1991), which yields exposure amplitudes and durations concomitantly. In addition, we aimed to compare the measured exposure to self-reported low-back load, and to assess associations of measured exposures with self-reported LBP.

2. Methods

We recruited 104 surgical assistants in this study. Thirteen surgical assistants were excluded from the data analysis due to battery, storage, or data exporting errors. The other 91 surgical assistants were included in the data analysis. These surgical assistants worked in one of four hospitals: one university hospital (n = 22), two general hospitals (n = 27 and n = 29), and one orthopaedics clinic (n = 17), with the latter performing surgical procedures of relatively short duration. All surgical assistants worked in the sterile environment at the surgery table during the measurement. For surgical assistants who filled out a brief questionnaire (81%; see below), demographic data were recorded (65 females, 7 males; mean ± sd: age 43.6 ± 12.9 years; height 170.8 ± 8.4 cm). All participants signed an informed consent prior to the experiment. Ethical approval had been granted by the ethics review board of the faculty of Behavioural and Movement Sciences of the Vrije Universiteit (VCWE-2021-095).

2.1. Procedure

Before the start of the surgery, two IMUs (DOT, Xsens, Enschede, the Netherlands) were mounted on the participants using duplex body tape and Fixomull stretchable tape (Leukoplast). One IMU was located at 27.5% of the measured length from mid posterior superior iliac spines to spinous process C7 (approximately T12 vertebral level), which has been shown to be the best location to estimate the inclination angle of the trunk center of mass, in order to estimate the back loading caused by the force of gravity on the inclined trunk (Faber et al., 2013, Faber et al., 2009). A second IMU was placed on the pelvis, in between the two posterior superior iliac spines, but was not used in the current study.

For sensor calibration, participants were first instructed to adopt a natural upright stance and remain static for approximately 5 s. Subsequently, a walking trial was performed, which consisted of walking 10 m in a straight line at preferred pace. Participants were asked to stand still without turning at the end of the 10 m walk after which a second standing measurement was collected. In case of an incorrect execution of these calibration measurements, participants were asked to perform the same tasks again. During these pre-surgery measurements, the sensors sampled data at a rate of 60 samples/s.

The observational measurement was started when the participants (with the mounted IMUs) left for the surgery. Data were recorded at a rate of 15 samples/s, to avoid exceeding maximum storage. Participants were asked to monitor the time between the start of the observational measurement and the actual start of the surgery in sterile position (by noting the time on a clock).

As soon as the surgery ended, participants returned to have the IMUs removed and the measurement stopped. Participants were asked to complete a brief questionnaire (immediately or as soon as possible after the surgical procedure; in Dutch) regarding perceived low-back load during the measured surgical procedure (scale 1–10; with (converted to English) 1–10 as 'no load', 'very light', 'light', 'moderate', 'reasonable', 'considerable', 'little heavy', 'heavy', 'very heavy', 'maximal', respectively), self-reported duration of persistent or repeated LBP (no pain; < 6 months; 6 months–1 year; 1–3 years; 3–5 years; > 5 years), self-reported LBP after an average work day (scale 1–10; with (converted to English): 1 as 'no pain', 10 as 'pain as bad as you can imagine' (Dworkin et al., 2005)), and whether, on average, the load during the measured surgical procedure was representative of a typical surgical procedure (scale 1–10 with 1 as 'much lighter', 3 'lighter', 5 'similar', 8 'heavier', 10 'much heavier').

2.2. Data processing

The exported data from the two IMUs consisted of time series of three-dimensional (1) orientation, in quaternions, relative to the global earth coordinate system, and in the local sensor coordinate system, (2) linear acceleration (including gravity), (3) angular velocity, and (3) magnetic field. IMU data timeseries were cut to remove the sections before and after the surgery. Using the linear acceleration data recorded during the 10 m walking trial, the quaternion data of both sensors were aligned to a fixed axis system of the trunk, with its vertical axis (Y) aligned with the gravity vector, X axis in the walking direction, and Z axis perpendicular to the X-Y plane (Rispens et al., 2014). The quaternion data recorded during the static trial was used to obtain the quaternion orientation relative to natural upright stance.

Subsequently, three-dimensional Euler angles of the trunk relative to natural upright stance were obtained using a decomposition order Y (heading), X (lateral inclination), Z (backward/forward inclination).

For the trunk inclination angle in the sagittal plane, a custom Exposure Variation Assessment (EVA) function (Mathiassen & Winkel, 1991) was used to express the percentage of the total surgery time continuously spent in five specific ranges of angle (< -10° (backward inclination); -10 to 10° (upright posture); 10 to 20° (light inclination); 20 to 30° (moderate inclination); > 30° (strong inclination)) for four specific ranges of posture duration (i.e., time: < 10 s, 10 s to 60 s, 60 s to 300 s, > 300 s).

2.3. Statistical analysis

Per participant, for the EVA analysis of the trunk inclination angles, the percentage of total surgery duration in a specific angle bin (5 bins) for a specific time bin (4 bins) was calculated. Additionally, sum scores (of these percentages) of angle bins (over all time bins) and time bins (over all angle bins) were calculated. Across participants, per computed bin, median and interquartile range values were calculated. For participants who completed the questionnaire, linear regression was used to evaluate the relationship between the percentage of the total surgery duration exceeding a trunk inclination angle of either 10°, 20° or 30° and questionnaire answers. In addition, a sign test was performed to evaluate whether the self-reported load of the measured procedure was different from an average procedure.

3. Results

Over 91 surgical assistants, the average duration of the surgical procedure was 174 min [77–251 min] (median [interquartile range]). The EVA analysis for trunk inclination in the sagittal plane (Fig. 1) showed that surgical assistants were mainly in upright posture around the neutral upright posture, i.e. for 75% [63–84%] of the surgery duration between -10° and 10°. Moreover, whenever trunk inclination exceeded 10°, the duration of trunk inclination within the considered angle bins (10°–20°, 20°–30°, and > 30°) was almost always less than 60 s (Fig. 1).

Over the whole surgical procedure, the average total duration of trunk inclination, i.e. inclination angle beyond 10°, was 14% [8–28%] of the surgery duration. Trunk inclination was beyond 20° for 4.3% (2.1–8.7%) of the surgery duration, and exceeded 30° for only 1.5% [0.5–3.2%] of the surgery duration (Fig. 1). Out of 91 participants, 18 exceeded 20° trunk inclination for over 10% of the surgery duration, and 6 exceeded 30° trunk inclination for over 10% of the surgery duration.

The questionnaire response rate amongst the included participants was 81% (74 out of 91). Results from these questionnaires indicated that most of the respondents (72%) had over 10 years work experience as a surgical assistant, whereas only 3% had less than 1 year work experience. Most participants (73%) worked more than 25 h per week as surgical assistant. Perceived back strain during the measured surgical procedure did not significantly deviate from the perceived back strain of an average surgical procedure ($p = 0.522$; 43% scored normal, 25% scored heavier and 32% scored lighter). Furthermore, 49% indicated to have persistent or repeated LBP with, 12%, 16% and 20% of the respondents reporting LBP for less than a year, 1–5 years, and more than 5 years, respectively. When asked to rate LBP (on a scale 1–10) after an average work day, 74% scored higher than 1, and 20% scored above 4.

For the participants that completed the questionnaire, individual data of total percentage trunk inclination (> 10°, > 20° and > 30°) during the measured procedure were plotted against (1) self-reported low-back load during the measured surgical procedure, (2) self-

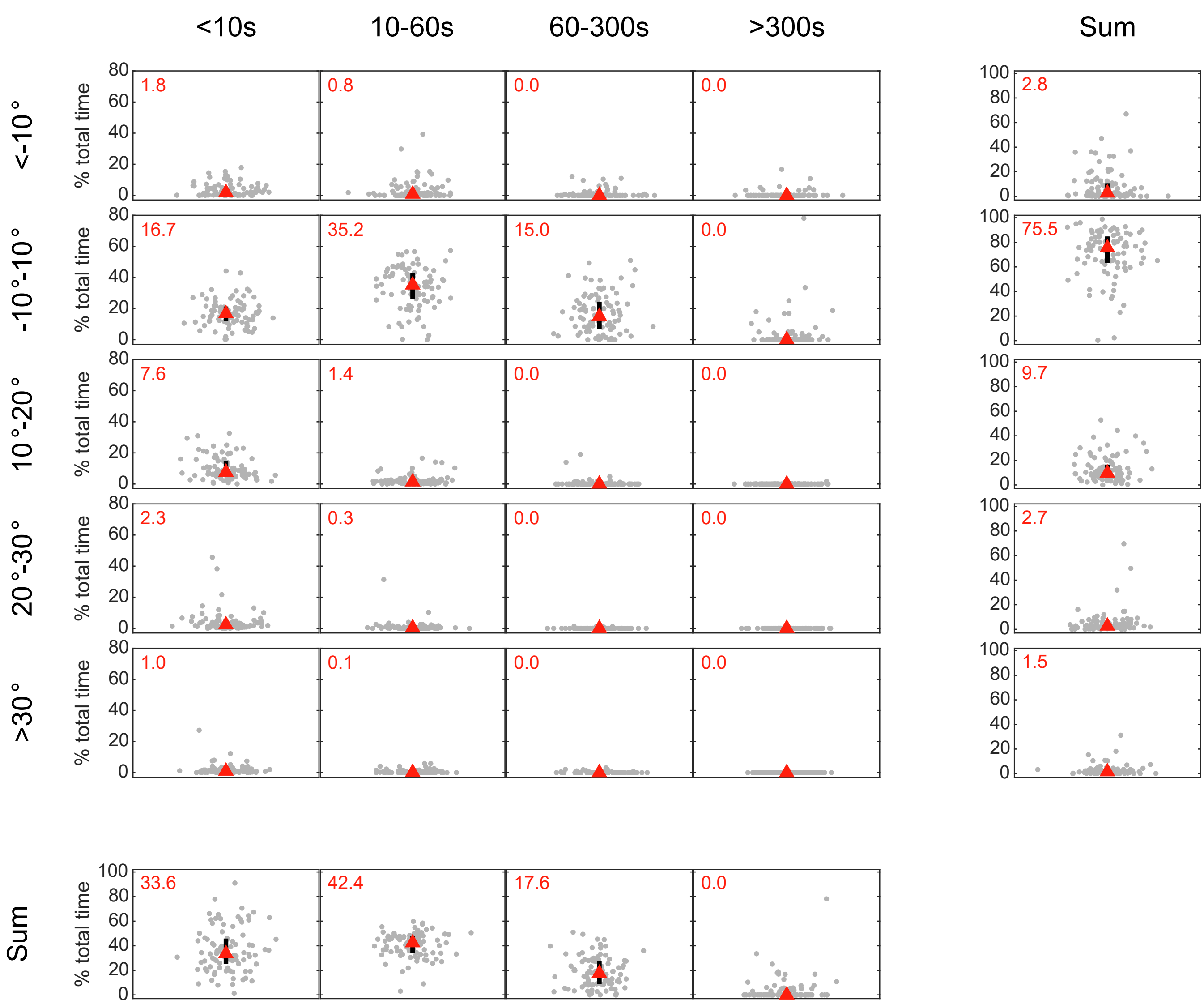

Fig. 1. The Exposure Variation Assessment (EVA) (Mathiassen & Winkel, 1991) of the trunk sagittal plane inclination angle which expresses the percentage of the total surgery duration continuously spent in five specific ranges of angle (< -10°, -10° to 10°, 10° to 20°, 20° to 30°, > 30°) for four specific ranges of time (< 10 s, 10 s to 60 s, 60 s to 300 s, > 300 s). The last column and row depict the sum over columns and rows, respectively. The median (red triangle and red number in upper left corner) and interquartile range (black line) are depicted. To illustrate the between-subject variability, individual data points are depicted with a random jitter along the horizontal axis. Note that the vertical axis limits of the individual time-angle subplots and sum subplots are different (0–80% and 0–100%, respectively).

reported LBP pain after an average work day, and (3) self-reported LBP history (Fig. 2). Neither of these analyses yielded a significant relationship ($R^2 < 0.1$, $p > 0.2$).

4. Discussion

We measured trunk inclination in 91 surgical assistants using wearable IMUs, and found that they were working in inclined trunk postures for only a minor percentage of the measured surgical procedure, with median values below 5% and 2% of the surgery duration for > 20° and > 30° of trunk inclination, respectively. Moreover, trunk inclination between 20° and 30°, or > 30° was mostly of short duration (i.e. less than one minute). Finally, trunk inclination exposure was not associated with perceived low-back load of the measured surgical procedure, self-reported LBP after an average work day, and self-reported LBP history.

The trunk inclination exposure reported by previous studies in nursing (Freitag et al., 2007; Nourollahi et al., 2018) and surgeons (Meltzer et al., 2020; Yang et al., 2021) may not be representative for the population of Dutch surgical assistant of the current study. In nursing much higher percentages of inclined postures have been reported, trunk inclination beyond 45° ranging from 10% to over 50% across nursing departments (Freitag et al., 2007; Nourollahi et al., 2018). For surgeons median trunk inclination exceeding 20° was reported for 15 % to 35 % of the surgery duration (Meltzer et al., 2020; Yang et al., 2021), with the lowest value representing laproscopic surgery (Yang et al., 2021). In contrast, we found a median of 5% of surgery duration, and in only 18 out of 91 participants trunk inclination exceeded 20° for more than 10% of the surgery duration. As the participants in this study were involved in a wide range of surgical procedures, it seems unlikely that the difference with surgeons in other studies was due to specific surgical procedures. Possibly, surgeons are more often in (prolonged) inclined trunk postures because they need a better view of the operation area. Also, surgeons may on average be taller, as in these studies the proportion of males was larger (64% and 51% for Meltzer et al. (2020) and Yang et al. (2021), respectively) than in our population of surgical assistants (10%). Further, possible differences in ergonomic conditions in the surgery room across countries or hospitals, or over time, may explain our contrasting results when compared to previous studies. Finally, we cannot exclude that methodological differences between studies have played a

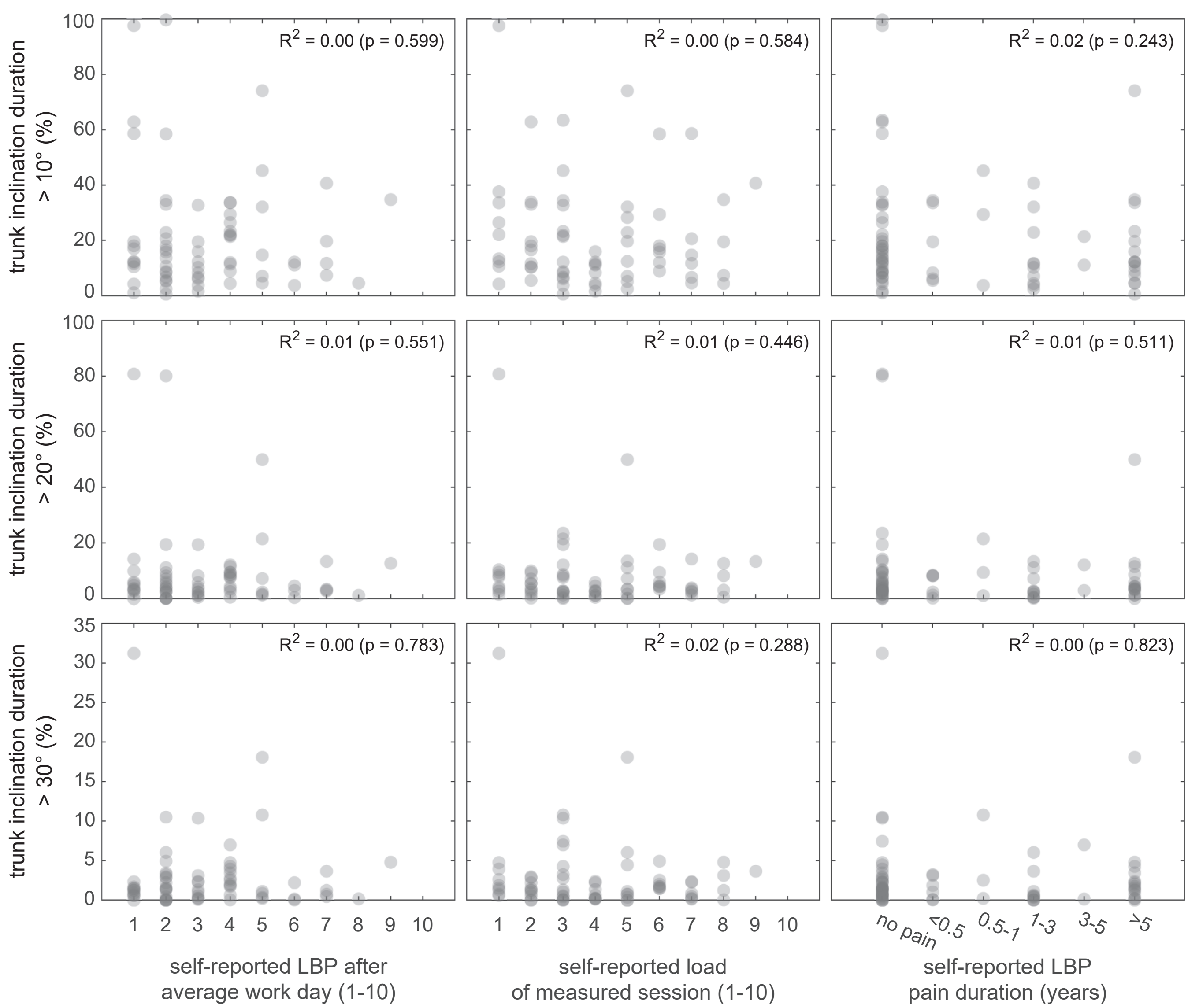

Fig. 2. The percentage of the total surgery duration exceeding a trunk inclination angle of either 10° (first row), 20° (second row) or 30° (third row) and self-reported low-back pain after an average work day (first column), perceived low-back load of the measured surgical procedure (second column), self-reported duration of low-back pain (third column). Linear regression results (R^2 and p-value) are depicted in the upper right corner.

role. Previous studies that measured trunk angles in surgeons (Meltzer et al., 2020; Yang et al., 2021) used sensor locations about half way the thorax. We used 27.5% of the height from L5S1 to C7. This location is suggested to best represent the inclination of the line from the lumbosacral joint to the trunk center of mass relative to upright posture (Faber et al., 2013, 2009). A sensor location at 50% instead of 27.5% trunk height would result in about 10 % increase in estimated trunk inclination angle (Faber et al., 2013). Therefore, a different sensor location may explain in part differences with previous studies (Meltzer et al., 2020; Yang et al., 2021). Also, Yang et al. (2021) computed the angle of the trunk relative to the gravity vector instead of neutral upright stance, which may in part explain differences between their reported trunk inclination angles and trunk inclination angles presented in the current study.

Out of the 74 surgical assistants completing the questionnaire, 49% reported persistent or repeated LBP. This percentage is similar to Meijsen and Knibbe (2007) who reported 46% of 463 surgical assistants in the Netherlands to have experienced LBP in the last 3 months. Previous studies reported a 12 month prevalence of 50–70% reported for surgeons (Epstein et al., 2018; Meijsen & Knibbe, 2007; Szeto et al., 2009). These numbers are higher than the 12 month prevalence of 38% reported for the general population (Hoy et al., 2012). This does suggest that both surgeons and surgical assistants have an increased risk of developing LBP.

The ISO 11226 norm indicates that postures with a trunk inclination less than 20° are always acceptable, whereas the acceptable duration decreases linearly from 4 min to 1 min with a trunk inclination angle increase from 20° to 60° (International Organization for Standardization, 2000). However, our data suggest that the overall percentage of time in inclined postures (2% > 30°) is well below risk factor levels reported in previous work (10% > 30°; Hoogendoorn et al., 2000). Similarly, considering the duration of inclined postures, our EVA analysis (Fig. 1) indicated that trunk inclination angles exceeding 20° were only in a few cases maintained for more than one minute.

For participants completing the questionnaire, we found no relation between measured trunk inclination exposure and perceived low-back load of the measured surgical procedure. Although the trunk inclination exposure was generally limited, participants reported a considerable low-back load during the surgical procedure, suggesting other factors than the low-back load due to trunk inclination exposure played a role. This does underscore the importance of using, in parallel to subjective, IMU-based or similar objective estimates of low-back load in future research on LBP risk factors.

All in all, our reported exposure of surgical assistants to inclined postures does not explain the high prevalence of LBP in this population, suggesting that other risk factors play a role. For instance, a previous *meta*-analysis indicated that prolonged occupational standing (> 4 h per work day) is associated with an increased risk of developing LBP (Coenen et al., 2018). Additionally, applying forces with the hands during surgery work, or carrying and lifting equipment when assisting in non-sterile position, could induce high low-back loads. Note that in the Netherlands surgical assistants never switch between sterile (i.e., at the surgical table) and non-sterile position (i.e., providing equipment to the surgical team) within one surgery, but do perform the non-sterile tasks in about half of the surgeries. While we did not systematically document this, many of the measured participants indicated that carrying and lifting (e.g., surgical tools/equipment) during non-sterile tasks can be heavy.

Several limitations of this study should be noted. While it is plausible that the type of surgery affected the exposure to inclined postures, we were unable to conduct subgroup analyses on the type of surgery. This was due to the large variety of surgeries investigated, as well as the inaccurate description of the self-reported surgery type. Furthermore, in many cases, there was no time to fill out the questionnaire immediately after surgery. Therefore, in some cases, there was a delay up to a few days in completing the questionnaire, which may have caused recall bias for questions specifically relating to the measured surgical procedure. Moreover, 19% of the participants did not complete the questionnaire, and therefore could not be included in analyses related to questionnaire data.

In conclusion, using inertial measurement units, we showed that surgical assistants were, during their work at the table, only for a minor proportion of the time exposed to substantially inclined trunk postures, and these postures were short-lasting. Additionally, the measured trunk inclination exposure was not associated to self-reported low-back pain. Therefore, the mechanical low-back loading due to inclined trunk postures may not explain the high prevalence of low-back pain in this population. Finally, IMUs appear to be suitable for larger field studies, even in environments such as the surgery room, where zero hindrance during work and minimal preparation time must be guaranteed.

CRediT authorship contribution statement

N.P. Brouwer: Conceptualization, Data curation, Writing – original draft, Writing – review & editing, Visualization, Investigation, Validation, Formal analysis, Methodology, Resources, Project administration, Software. **I. Kingma:** Conceptualization, Data curation, Writing – original draft, Writing – review & editing, Visualization, Investigation, Validation, Formal analysis, Methodology, Resources, Supervision. **W. van Dijk:** Writing – review & editing, Visualization, Validation, Methodology, Supervision. **J.H. van Dieën:** Conceptualization, Writing – original draft, Writing – review & editing, Investigation, Formal analysis, Methodology, Supervision, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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