Low Back Pain in Microgravity and Bed Rest Studies

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BACKGROUND: The prevalence of low back pain (LBP) for astronauts in space (68%) is higher than the 1-mo prevalence for the general population on Earth (39%). It is unclear whether differences occur between healthy subjects and astronauts with a history of LBP. Knowledge of this issue is important to assess whether a history of LBP could have an operational impact.

METHODS: We evaluated LBP prospectively during short duration spaceflight (15 d; $N = 20$) and compared this with similar data collected during two bed rest studies ($N = 40$). Astronauts completed a questionnaire 5–10 d preflight, during each flight day, and 5–10 d postflight.

RESULTS: All astronauts with a history of LBP also developed LBP in flight. These astronauts reported a significantly longer duration of LBP and a different pain location. LBP was most often experienced in the central area of the lower back during spaceflight with an incidence of 70% and a mean pain level of 3 (on a scale of 0–10). Pain resolved within 10 d of flight. No neurological signs were present. The most frequently reported countermeasure was assuming a "knees to chest (fetal tuck) position" combined with stretching. Greater LBP intensity was reported in spaceflight than bed rest with a trend indicating a greater number of days of pain during spaceflight.

DISCUSSION: The current study represents a prospective study of LBP in spaceflight. The results indicate that LBP is self-limiting in spaceflight and should not pose an operational risk. Prior LBP on Earth appears to be a risk factor for LBP in spaceflight.

KEYWORDS: Low back pain, microgravity, intervertebral disc.

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Astronauts exposed to microgravity frequently report low back pain (LBP). According to the literature 52–68% of astronauts develop LBP during short-term spaceflight.[19] This is higher than the 1-mo prevalence of LBP typically reported in the general population on Earth (39%).[14] The most detailed work on LBP to date is a retrospective study of 19 astronauts reporting in-flight back pain.[19] These subjects described the pain as dull (62%), localized to the lower back (50%), with a mean intensity of two on a five-point scale. The duration of pain varied from 14 to 100% of the flight. Such pain may jeopardize a crewmember's performance in orbit since it can have an impact on mood status, as demonstrated during simulated microgravity.[16] A prior review has argued that low back pain may hinder an astronaut's ability to perform challenging tasks by disrupting sleep and subsequently mental concentration.[15] With space agencies and governments around the world moving toward manned missions to Mars, LBP may be a health concern. However, basic information measured in a prospective study is lacking on the natural course and development of LBP during spaceflight. Furthermore it is not known how a history of LBP prior to flight will affect LBP in space.

The aim of the current study is to describe prospectively the development and course of LBP in microgravity in full detail regarding onset, localization, severity, and relieving countermeasures undertaken by astronauts per day in short-term flight. We compared the development and course of LBP between astronauts with a history of LBP prior to flight versus healthy astronauts (no LBP). We also aimed to compare data from spaceflight to data on LBP published in two bed rest studies.[1–3] Our primary hypothesis was that LBP in microgravity is self-limiting.

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METHODS

Subjects

Astronauts participating in a spaceflight as well as volunteers participating in two separate bedrest studies enrolled in the study. For convenience, astronauts, cosmonauts, and volunteers were included in the study. No sample estimates were calculated. Permission for the conduct of the studies was given by the Medical Ethical Committee of Erasmus MC University, Rotterdam, The Netherlands, and the Medical Ethical Committee of Charité Universitätsmedizin, Berlin, and the Aerztekammer Nordrhein, Düsseldorf, Germany. All subjects gave their written informed consent.

Questionnaires

Using an LBP questionnaire, the development of low back pain in astronauts and cosmonauts during spaceflight was assessed to gain insight in the development, location, severity of LBP, neurological signs and possible countermeasures astronauts and cosmonauts develop for themselves. Localization was tested with a pain drawing and a pain Numeric Rating Scale (NRS) from 0 (no pain) to 10 (excruciating pain) was added to measure the intensity of pain.[12] Both drawing and NRS have been demonstrated to be valid and reliable measurements.[11,13] Two open questions were added to ask for provoking periods during flight and to ask about what countermeasures the astronaut undertook. Two yes/no questions were added to ask for any neurological signs like pins and needles or pain radiating into the leg, and one yes/no question asked for the continuity of pain (present whole flight day). A final yes/no question was added to ask for the use of any pain medication.

Procedure

The questionnaire was completed by astronauts 10 d ($\pm$ 5) prior to the flight, each day during the 12- to 15-d flight, as well as 10 d ($\pm$ 5) postflight. At 3 to 6 mo postflight, a debriefing was scheduled to determine the effectiveness of the countermeasures for the astronauts who experienced LBP. Two questions were added postflight during the debriefing: “Did you experience any LBP during your life prior to the flight?” and “Did you do any training in the International Space Centre ISS?”

To compare data of LBP in microgravity with LBP experienced in simulated microgravity, the LBP-questionnaire was also part of questionnaires used in two bed rest studies,[1–3] although in both studies a pain Visual Analog Scale (VAS) was used instead of a pain NRS. Both instruments test sufficient for reliability, test-retest.[6] Further, both instruments demonstrate high construct validity ranging from 0.71–0.78.[6] Before, during, and after each bed rest study the questionnaires were filled in, although pre- and post-bed rest measurements differed in number and days compared to the in-flight study. Also, the duration of microgravity (12–15 d) was different from the duration of the bed rest studies: in one case 60 d (in Berlin, Germany[1,2]) and in the other 21 d (in Cologne, Germany[3]). To be able to compare all studies only the first pre-bed rest test results, the results of the first 15 d of bed rest, and the post test results of the 5th day were used for analysis.

Data from the pain drawing was divided into five different pain localizations:

1) pain in the surrounding of the iliac crest at the posterior iliac spines on both sides;
2) LBP in a broad central lower lumbar region;
3) pain in a small area at the height of the iliac crest and L5;
4) pain at the level of L1-L3; and
5) pain in the buttocks.

Data from provoking periods was divided into six different categories:

1) unknown;
2) being strapped for long time (sleeping);
3) static posture not using the back for a long time;
4) during or after walking or running;
5) work position; and
6) straightened back.

Data on helpful countermeasures was divided into 7 different countermeasures:

1) unknown;
2) daily regular exercise;
3) fetal tuck (full flexion knees to chest);
4) moving around;
5) stretching;
6) full flexion combined with full flexion (fetal tuck); and
7) pain medication.

Statistical Analysis

The occurrence, localization, intensity, continuity, and duration of LBP has been described for all subjects and tested for significant difference between astronauts experiencing LBP with no history of LBP on Earth and those who experienced LBP in their life prior to flight using Wilcoxon ranking for the dichotomous variable and ordinal variable and the Student *t*-test for the continuous variable (NRS, duration). Descriptive data on provoking movements or periods and successful countermeasures undertaken by astronauts will be described. Data on LBP in flight was compared with data on LBP collected in previous bed rest studies[1–3] on pain VAS and pain drawing. To be able to compare the data on the pain NRS and pain VAS, scores on both lists were expressed as percentages of maximum score. Unless otherwise stated, values are reported as mean (SD). An alpha level of 0.05 was taken for statistical significance. The PASW 17.0 software was used for statistical analyses.

RESULTS

Data were recorded for 20 astronauts during 10 different flights (5 Soyuz missions from 2004-2007 and 5 Space Shuttle missions from 2007-2010). The duration of flights ranged from 11

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to 15 d. In five astronauts, data of the last 4 flight days were missing. One astronaut reported this was due to stowing the paper questionnaire in the Soyuz while staying in the ISS. During the debriefing postflight all of these four astronauts stated they did not experience LBP in the last flight days. All astronauts reported having used the treadmill in the ISS for training activities. Socio-demographic data of all astronauts and cosmonauts are shown in **Table I**.

None of the astronauts reported any LBP 5–10 d prior to flight. Data on development, intensity, and continuity of LBP, and the presence of any neurological signs per flight day are shown in **Fig. 1**. In all astronauts LBP was self-limiting. No LBP occurred after flight day 9.

Overall, 14 astronauts (70%) experienced LBP with a mean of 5 d of pain ($\pm$ 2 d). Of the 14 astronauts experiencing LBP, 8 had a history of LBP on Earth prior to the flight. None of the astronauts without pain in flight had a history of LBP on Earth. Mean intensity of pain on the pain NRS was 3 ($\pm$ 1). The highest score on a pain NRS was 7 out of 10 on flight day 1 in one astronaut with a history of LBP on Earth. This astronaut reported that the severe LBP was interfering with his mental concentration. There were 29% of the astronauts who reported pain in the surrounding iliac crest at the posterior iliac spines on both sides, 38% reported LBP in a broad central lower lumbar region, 20% reported pain in a small area at the height of the iliac crest and L5, 9% reported pain at the level of L1-L3, and 4% reported pain at the buttocks. The main provoking activities associated with LBP were unknown in 38%. In 45% pain was reported after sleeping and in 7% pain provocation was associated with maintaining a static posture. The most relieving countermeasures were fetal tuck (rolling up to full flexion) combined with full extension in 30%, fetal tuck (knees to chest) alone in 19%, moving around in 15%, painkillers in 15%, and stretching in 5%. During debriefing all astronauts pointed out that they had used the treadmill during their stay in the ISS. The reason for running on the treadmill was given as the urge to be active and not as a direct countermeasure for LBP. Some astronauts reported that running exercises might have helped to prevent LBP.

Data on the use and effect of pain medications are missing in three astronauts since paper copies of the questionnaire were made without the last question. One of these three astronauts experienced LBP. A total of nine astronauts used pain medications, although two reported the use of these drugs as part of the EVA protocol while they did not experience any pain at all. Of the remaining seven astronauts using pain medication, three reported using painkillers due to headaches. Of the four astronauts using pain medication for LBP, two (15%) reported pain relief due to these drugs. No neurological signs were reported.

Table I. Participants and low back pain (LBP) characteristics.

	ASTRONAUTS	BED REST SUBJECTS
N	20	33 (40 datasets)
Gender, Male/Female (N)	17/5	100/0
LBP occurrence, N (percentage of total)	12 (60%)	22 (67%)
History of LBP, N (percentage of total)	8 (40%)	15 (45%)
Age (mean $\pm$ SD)	47 $\pm$ 6 yr	31 $\pm$ 8 yr

Two astronauts reported LBP postflight (5–10 d) in the first 4 d after flight with a mean intensity of two on the NRS. One astronaut stated that the pain was relieved during daily activities and running, while the other reported experiencing a relief with massage. Both had a history of LBP prior to the flight.

Of the eight astronauts who already experienced an episode of LBP on Earth, all experienced LBP during flight (prevalence 100%). Of the 12 astronauts without a history of LBP prior to flight, 4 did experience LBP in flight. A significant difference was present between astronauts with a history of back pain compared to those without concerning the number of days experiencing LBP ($P < 0.01$). A mean of 5 d of experiencing LBP was reported in the "history of LBP group" compared to 2 d in "the first time LBP group." Another significant difference between both groups was demonstrated in the pain location ($P < 0.05$). In 50% of the astronauts experiencing LBP for the first time, pain was described in the upper regions of the lumbar spine, a small area covering L1-L3. In the "history of LBP group," 46% experienced pain in the lower back in the area surrounding the iliac crest at the posterior iliac spines on both sides, and 30% in a broader area of the lower lumbar spine. No significant difference was reported in pain onset, intensity, pain provocation, or in relieving countermeasures undertaken by astronauts.

A total of 33 subjects participated in two bed rest studies resulting in 40 datasets (Table I). There were 24 subjects who participated in the second Berlin bed rest study. Seven subjects participated in the Cologne bed rest study consisting of two consecutive campaigns (cross over design) leading to 14 datasets, plus 1 dataset from a subject in the first campaign (dropped out on day 30 after bed rest) and 1 subject in the second campaign. From the 33 subjects a total of 15 subjects reported one or more episodes of LBP prior to the bed rest study (one from a spinal fracture). Of these 15 subjects, 4 also reported LBP on the pretest with a mean pain of 17 mm on the pain VAS and one of the subjects with no history of LBP reported pain on the pretest (22 mm on pain VAS). During the first 15 d of all bed rest study campaigns a total of 22 subjects (67%) reported LBP with a mean duration of 4.5 d (min 1 d, max 15 d) and a mean score of 22 mm on the pain VAS ($\pm$ 12.6 mm SD) with most subjects experiencing pain on day 2. Out of 12 subjects known to have LBP prior to the study, 6 did not experience any LBP during the study. The mean pain intensity for the other 6 subjects was significantly higher with respect to the 16 subjects experiencing LBP for the first time during the bed rest study (26 mm $\pm$ 12.8 vs. 18.6 mm $\pm$ 11.6 SD). Also, the number of days in pain was significantly higher ($P < 0.05$) in subjects with history of LBP than in those subjects with no history of LBP (5 d $\pm$ 4 vs. 2 d $\pm$ 2). One subject experienced constant pain every day. All subjects reported LBP in the central region of

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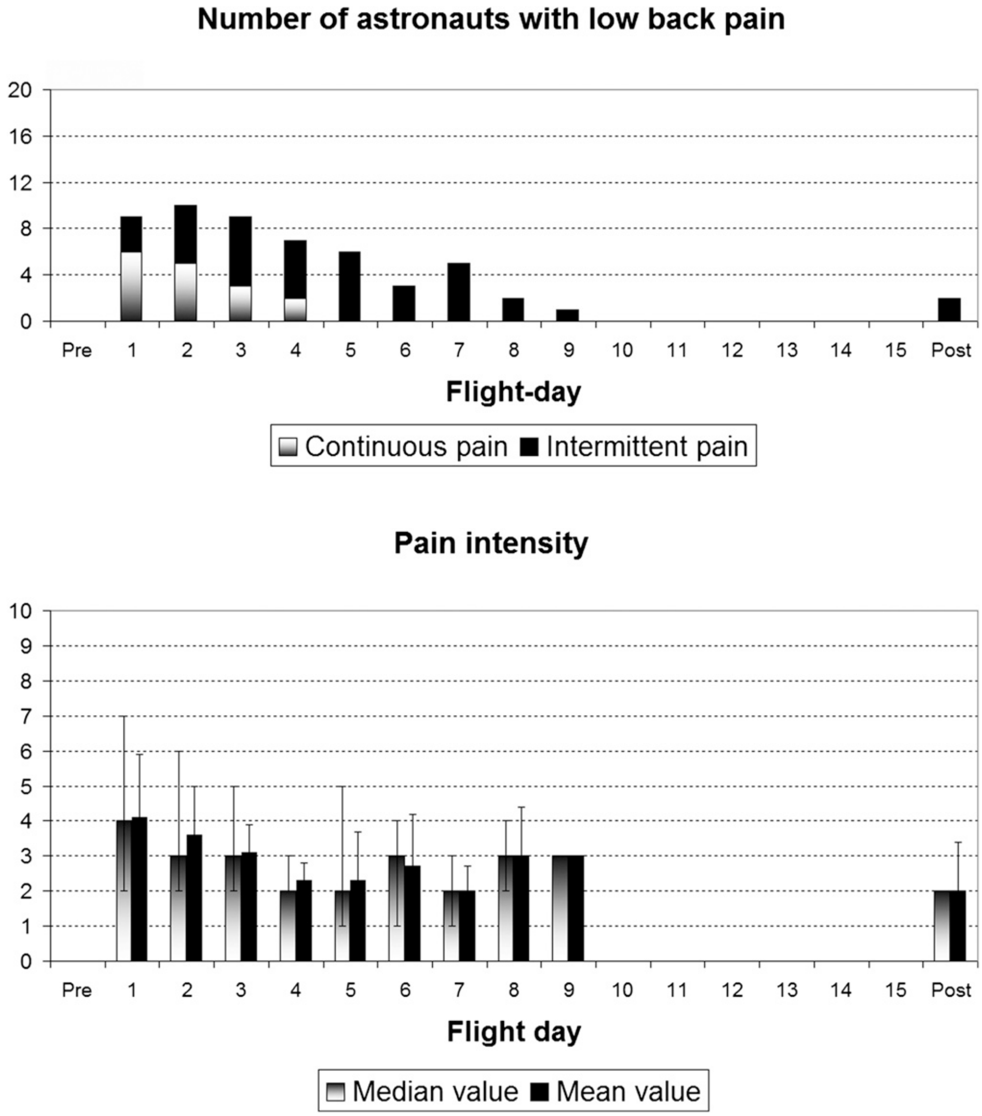

Fig. 1. The incidence (upper) and intensity (lower) of low back pain in 20 astronauts in 15-d spaceflight. Upper: data have been separated into number of astronauts experiencing pain constantly throughout the flight day or only intermittently. Lower: both median and mean values from all astronauts reporting pain are reported. Error bars indicate SD. No astronauts reported any symptoms indicating neurological involvement.

the lumbar spine. One of the subjects could not report any provoking moments or relieving countermeasures. Other subjects reported more frequent turning as a successful countermeasure. No neurological signs were present in the subjects. In a total of 8 subjects, LBP was present in the post bed rest phase with a mean of 29.2 mm on the pain VAS (± 13.1 mm). Of these 8, 5 also experienced LBP during the bed rest and had a history of LBP while 3 did not experience any LBP prior to or during the bed rest study.

Comparing data on LBP in space with bed rest demonstrated a difference between the two groups since no pain was present in astronauts on the preflight test while five bed rest subjects already reported LBP at the pretest. These five subjects were excluded from subsequent comparisons between spaceflight and bed rest to avoid a confounding effect by the presence of LBP. For those days in pain, a significantly greater intensity of LBP was experienced in space (mean score 30 ± 12.7% vs. 21 ± 12.3%), a trend could be seen on a longer duration of LBP in space (4 d ± 2 vs. 3 d ± 2 in bed-rest subjects).

DISCUSSION

The most important new finding of the current study is that there is a 100% prevalence of LBP during spaceflight in astronauts with a history of LBP prior to flight. Since all of these astronauts reported "non-specific" LBP, we were not able to relate the findings to what pathology may have been present. A number of factors, such as disc and facet joint pathology, different muscle motor patterns of the muscles of the trunk, and alterations in nociceptive system processing,[5,7,10] may be associated with these effects in spaceflight. The underlying mechanism of pain occurrence is most likely the sudden lengthening of the spine, studied well in bed rest,[8] and thought to occur in spaceflight along with overall increases in body height.[18,20] On the basis of our findings, prior incidence of low back pain should be considered a risk factor for low back pain occurrence in spaceflight, and even more so since the highest pain level as reported was interfering with mental concentration.

In line with earlier studies, LBP is a self-limiting problem in spaceflight.[9] No astronaut reported any LBP after 9 d of flight. We hypothesize that this is because of full adaptation of the lumbar spine and ligamentous tissues to functioning in a microgravity environment. Of all astronauts in the current study, 70% reported LBP, which is in line with data from an earlier retrospective analysis,[19] although Kerstman et al.[9] reported a prevalence of 52%. The difference in prevalence rates might be due to the high number of astronauts with a history of low back pain in our study. The number of astronauts with a history of LBP prior to flight is not reported by Kerstman et al.[9] Furthermore, in their retrospective analysis, only Space Shuttle astronauts consistently completed a low back pain questionnaire, whereas for the remaining programs, a chart audit was

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performed. This could have resulted in some under-reporting of back pain.

It was demonstrated that in all astronauts experiencing LBP, the pain started from day 1 as soon as exposure to microgravity commenced. Highest pain intensity was scored on day 1 as well, median 4 on NRS. The highest score (7) on the NRS was also on day 1. This was not different between the two LBP groups (with and without history of LBP) nor was pain intensity. As mentioned this astronaut reported that this severe LBP was interfering with his mental concentration. However, this is reported in only one astronaut, therefore we cannot speculate on safety measures. Differences between the two groups occurred in pain localization. A broader area of pain in the lower back was experienced in the "history group" while a smaller area higher up in the lumbar spine (L1-L3) was mostly reported in the "first LBP group." We expect that tissues already affected will be more vulnerable to all changes which occur during adaptation as described above. For the "first LBP group," LBP was experienced in the region where most flexion occurs in the lumbar spine (L1-L3), taking into account the prolonged stooped position of the spine in microgravity. We speculate that elongation of the spine combined with the more flexed position at L1-L3 increased tension in the dorsal ligamentous structures and annulus fibrosus, stimulating the sinuvertebral nerves of the discs and ligaments of the spine. Another significant difference between two groups was the duration of LBP. We hypothesize that in those with a history of LBP the affected tissues have been less able to adapt to microgravity. Conversely, only those without any prior low back pain have a chance of experiencing microgravity without any pain (30%).

We expected an influence of EVA on LBP in space. This was, however, not reported in the two astronauts who carried out EVA. We cannot draw any conclusions since both used painkillers according to protocol and due to the small sample size. In our study, differences in occurrence of LBP related to gender could not be tested for significant difference due to the small sample size. However, reported pain levels and intensity are very similar in men and women.

In our current study, most pain and provocation was reported after sleeping. During sleeping most astronauts are strapped to the wall (to avoid drifting around) or sleep in specially designed cabinets. Some astronauts try to sleep with their knees strapped in flexion. None of the astronauts was able to turn or, as we speculate, did they feel the urge to turn over during sleeping. This will result in a long period > 8 h of movement deprivation. It is likely that the intervertebral discs will increase in height and ligaments will be fully stretched by elongation of the spine.[17,18,20] This may be why most astronauts report that stretching to full extension combined with a fetal tuck is most effective as a countermeasure.[9,19] However, fetal tuck on its own has been reported to be a less favorable countermeasure than fetal tuck combined with stretching to full extension. We regard the need for a combination of full extension with full flexion as a sign that movement in the full range of motion is necessary as a stimulus for all tissues (discs, capsules, ligamentous tissues, nerves, and muscles) to normalize tension and restore normal function in a microgravity environment. Most astronauts report that it is hard to perform a full stretch in space since they are not able to anchor their feet. Maybe an adaptation could be made to the ISS to make this full stretch to extension easier to perform. Since, for astronauts, LBP is provoked most often by sleep, studying ways to decrease pain during sleep is recommended, because disruption of sleep interferes with concentration, decreases energy levels, affects mood, and may interfere with routine tasks.

As mentioned, all astronauts noted that they used the treadmill during their stay on the ISS for being active and not as a direct countermeasure for LBP. Some astronauts reported that running exercises might have helped to prevent LBP. Indeed, the study of Kerstmann et al. demonstrated a relief of pain in 85% of the astronauts who exercised.[9] We can only speculate on how this activity is related to the occurrence of LBP during flight and how this is related to LBP during a long stay in microgravity. We recommend this topic for future research. Since most astronauts report that pain is at its highest level after sleeping, a device could be developed to introduce a stimulus for astronauts to alter position of the spine during sleeping. Data from the bed rest studies suggest that short duration loading of the spine is not very effective in preventing morphological changes in the discs (for discussion see Belavý et al.[4]). We did not test morphological changes to discs and other structures in the astronauts pre- and postflight due to funding issues. Therefore, we are not able to compare morphological changes to discs during bed rest vs. the microgravity environment. However, we hypothesize that more continuous loading of the discs is important. A suit or vest that provides physiological loading of the spine and musculature during daily activities in microgravity could be developed. However, Russian cosmonaut experiences suggest that the comfort of such a device may be limited.[9] Hence, implementation of wearing a suit or vest could be considered specifically for astronauts with either known LBP that interferes with mission performance or those at risk. Also, pain medication as precaution during the first flight days could be beneficial.

The current study demonstrated that the occurrence of low back pain on Earth during bed rest is different from LBP in microgravity concerning pain intensity, and a trend has been demonstrated regarding duration. During bed rest, subjects still use their trunk musculature to move in bed. Hence, we hypothesize that the higher pain intensity in space could be related to more profound adaptations of the spine in spaceflight. It is also clear that a perfect 1:1 comparison between microgravity and simulated microgravity is not possible regarding the described countermeasures to diminish LBP. The most important countermeasure for bed rest LBP subjects was turning over while lying. This activity is impossible for astronauts in flight. None of the subjects in bed rest studies reported making movements in the spine from full flexion to full extension as being effective, while this is the most effective countermeasure in space. It seems that LBP on Earth, even during bed rest, cannot be compared to a microgravity environment.

The most important limitation of the current study is the limited number of subjects. While the sample size is quite

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large in comparison to typical spaceflight and bed rest studies, caution should still be used when applying the findings to wider populations. Nonetheless, the main findings are largely in agreement with other reports.[9,19] Another important limitation is the fact that in one of the bed rest studies, specific exercise protocols were performed. Although astronauts also perform countermeasure exercises, their protocols were undoubtedly different from those performed in the bed rest study. We were not able to obtain data on the performance of countermeasure exercise during spaceflight, hence, any confounding effect of exercise is unclear. Another limitation is the age difference between the astronauts and bed rest study subjects. One would expect some degeneration of lumbar spine function with age, however, astronauts are well trained and in good physical condition, despite their age. The difference between the two subject populations needs to be considered when interpreting differences between spaceflight and bed rest in LBP. Furthermore, selection bias might be present, although we regard the selection bias as minimal. All astronauts are selected prior to the study for their expertise and knowledge. They are extensively trained regarding protocols and physical fitness. After selection for a spaceflight program they are introduced to the studies in which they will participate. There is no self-selection for the studies performed during the spaceflight. However, selection bias in the bed rest subjects might be present, since they volunteered for the study. Finally, different pain measures were used in space vs. bed rest. The choice of comparable bed rest studies was made after the first pain measurement was carried out in space. Since the construct validity of both pain-measuring instruments is sufficiently high and compatible, it was decided not to alter the pain measurement tool already implemented in the space study.

In conclusion, the main finding of the current study was that LBP in spaceflight is a self-limiting condition. Another important finding was that prior history of LBP on Earth is a risk factor for LBP occurrence during spaceflight.

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