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Relationship between exposure to the natural environment and recovery from hip or knee arthroplasty: a New Zealand retrospective cohort study

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ABSTRACT

Objectives Determine whether patients who live in greener and more walkable neighbourhoods live longer, and take fewer opioids, following hip or knee arthroplasty.

Design Retrospective cohort study.

Setting Residential environment following surgery at one of 54 New Zealand hospitals.

Participants All people who received a total hip or knee arthroplasty at a publicly-funded hospital in New Zealand in 2006 and 2007 (7449 hip arthroplasties and 6558 knee arthroplasties).

Primary and secondary outcome measure Time to all-cause mortality and number of postsurgical opioid prescriptions.

Results Patients who lived in greener neighbourhoods, as measured by the Normalised Difference Vegetation Index, lived longer following hip or knee arthroplasty (standardised OR: 0.95, 95% CI 0.92 to 0.99). However, when we estimated separate hip-arthroplasty-only and knee-arthroplasty-only models, greenness was only significantly associated with greater longevity following hip arthroplasty. Similarly, patients who lived in greener neighbourhoods took fewer opioids in the 12 months following hip or knee arthroplasty (standardised OR: 0.97, 95% CI 0.95 to 0.99), but in separate hip-arthroplasty-only and knee-arthroplasty-only models, greenness was only significantly associated with lower opioid use following hip arthroplasty. Walkability was not significantly associated with postsurgical opioid use or postsurgical longevity. All ORs were adjusted for sex, ethnicity, age, presurgical chronic health conditions, presurgical opioid use, social deprivation and length of hospital stay.

Conclusions Consistent with the literature on enhanced-recovery programme, people who lived in greener neighbourhoods took fewer opioids, and lived longer, following hip arthroplasty. Improving access to the natural environment may therefore be an effective component of postsurgical recovery programme.

Strengths and limitations of this study

- ► First study to examine the relationship between natural environment and surgical recovery outside of a hospital setting.
- ► Large cohort followed longitudinally for 9+ years.
- ► Observational study, so a causal link between the natural environment and surgical recovery couldn't be established.
- ► Exposure was based on residential meshblock not residential address.

INTRODUCTION

Rates of hip and knee arthroplasty are rising globally. For example, in Organisation for Economic Cooperation and Development (OECD) countries, the incidence of hip arthroplasty rose from 140/100 000 people in 2005 to 164/100 000 in 2011.[1] Similarly, the incidence of knee arthroplasty in OECD countries rose from 114/100 000 in 2005 to 150/100 000 in 2011.[2] Increases in life expectancy and obesity rates suggest that this trend is likely to continue.[3] Given this increased demand, and constrained healthcare budgets, research has focused on identifying approaches that improve postsurgical health outcomes, shorten length of stay and reduce costs. For example, enhanced-recovery programme that emphasise rapid mobilisation and rehabilitation following hip or knee arthroplasty can reduce length of hospital stay[4] and decrease mortality.[5] However, no research has focused on the effect of patients' residential environments, despite the well-established link between exposure to the natural environment and increased physical activity,[6–9] and research showing that passively viewing a natural scene while recovering from surgery can reduce both length of hospital stay and postsurgical opioid use.[10] We address this gap in the literature by evaluating the relationship between exposure to the built and natural environment and recovery from hip or knee arthroplasty in a large New Zealand cohort.

Literature review

Numerous studies have examined how different elements of enhanced-recovery

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programme affect postoperative outcomes (also known as fast-track or rapid-recovery programme). These programmes use coordinated multimodal techniques to reduce recovery times and improve postoperative outcomes.[3] For example, preoperative education can shorten hospital stays[11] and reduce postoperative pain.[12] Several studies have found that pre-emptive analgesia allows more rapid mobilisation and return of function.[13 14] Multiple studies have found that rapid mobilisation on the day of surgery (typically 2 to 6 hours after surgery) reduces length of stay and improves function.[15–17] Similarly, aggressive physical therapy (extending beyond the day of surgery) can reduce length of stay and improve function.[18–20] Finally, in a prospective study of 4500 patients in the UK, enhanced recovery was associated with improved 2 year survival rates when compared with traditional postsurgical protocols, which suggests that postoperative mobility may have long-term benefits.[5]

Several studies have found that exposure to the natural environment is associated with increased physical activity. For example, using survey data in Chicago (n=1544), Fan *et al*[21] found that respondents with a greater area of public parks within 0.5 miles of their home were more likely to engage in physical activity. A survey of 1895 people in Adelaide, Australia,[9] found that respondents who perceived their neighbourhoods as greener were more likely to engage in recreational walking. Similarly, a study in 1803 people in Perth, Australia,[22] found that people who lived nearer to recreational amenities, including public parks, were more likely to meet minimum physical-activity requirements.

Passive exposure to the natural environment can also produce health benefits. In particular, several studies have found that greenness exposure can reduce perceived pain in a range of settings. Specifically, a randomised control trial (RCT) of 46 healthy volunteers[23] found that participants who had just watched a video of a natural scene had significantly higher pain threshold and tolerance than participants who had watched a blank screen. Similarly, a RCT of adults undergoing flexible bronchoscopy found that participants who viewed a natural scene reported significantly less pain.[24] Finally, an RCT of a 2 day forestry-therapy programme in Korea found that participants in the programme (n=33) had significantly lower levels of pain and depression than controls (n=25). In addition, participants had significantly higher heart-rate variability and natural-killer cell activity.

METHODS

Study sample

Our sample consisted of all people who received a total hip or knee arthroplasty at a publicly-funded hospital in New Zealand in 2006 and 2007 (7449 hip arthroplasties and 6558 knee arthroplasties). We obtained individual-level hospital and pharmaceutical records via Statistics New Zealand's Integrated Data Infrastructure (IDI), which is a large database of routinely-collected individual-level data.[25] The IDI is structured around a central spine designed to identify all New Zealand residents. Data sets describing health, education, benefits, criminal justice, population (births, deaths and immigration), income and work and housing are linked to this central spine.

As this study was based on routinely-collected health data, and did not involve contacting individual patients, the study was classified as minimal risk by the New Zealand Health and Disabilities Ethics Committee and was approved by Statistics New Zealand (MAA-2017-57). Before we were granted access, all data were anonymised by Statistics New Zealand. In addition, our research conformed to the Declaration of Helsinki guidelines.

Patient and public involvement

Neither patients, nor the public, were involved in the design or conduct of this study.

Outcomes

We used two outcomes to measure recovery: time to all-cause mortality and number of opioid prescriptions 3, 12 and 24 months postsurgery. We chose these outcomes as they are important metrics of postsurgical recovery. In addition, previous research has shown that rapid mobilisation and rehabilitation can reduce 2 year mortality rates following hip or knee arthroplasty,[26] and exposure to the natural environment, in a hospital setting, is associated with reduced perioperative use of opioids.[10]

By the end of 2016, 2263 (30.0%) of the 7449 people who had received a hip arthroplasty had died as had 1741 (26.5%) of the 6558 people who received knee arthroplasties.

The number of opioid prescriptions received was calculated by linkage to pharmacy records. We did not include prescriptions for methadone or buprenorphine, as in New Zealand these are primarily used to treat addiction. To control for presurgical pain, we calculated the number of opioid prescriptions each participant received in the 12 months before surgery. Finally, to account for opioid potency, we categorised each opioid prescription as either strong (potency equal to or greater than morphine) or weak (potency less than morphine). On average, study participants received 3.04 (SD=9.38) opioid prescriptions in the 12 months before surgery (0.68 strong and 2.36 weak) and 2.72 (SD=7.06) opioid prescriptions in the 12 months after surgery (0.75 strong and 1.98 weak).

Exposures

All exposures are based on a participant's residential meshblock, which is the smallest geographical unit at which Statistics New Zealand reports data. On average, 95 people live in a meshblock.

Linking to address history in the IDI allowed us to estimate exposures for each year of the study (2005 to 2016). From these annual values, we calculated mean postsurgical exposure, which we defined as the mean exposure from the year of surgery to death or 2016, whichever came first.

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Table 1 Descriptive statistics for study participants who received a hip or knee arthroplasty at a publicly-funded hospital in New Zealand in 2006 or 2007 (hip: n=7449; knee: n=6558)*

	Hip		Knee	
Variable	Mean	SD	Mean	SD
Male (%)	43.2	–	44.9	–
Race: NZ European (%)	82.0	–	81.1	–
Race: Māori (%)	9.9	–	6.4	–
Race: Pacific Islander (%)	0.99	–	3.2	–
Race: Asian (%)	1.53	–	1.56	–
Race MELAA† (%)	2.67	–	2.84	–
Race: Other/ Unspecified (5)	2.91	–	4.9	–
Chronic condition: COPD (%)	8.8	–	9.8	–
Chronic condition: acute MI (%)	5.8	–	5.1	–
Chronic condition: CHD (%)	10.6	–	12.1	–
Chronic condition: stroke (%)	2.3	–	2.6	–
Chronic condition: diabetes (%)	12.4	–	15.5	–
Chronic condition: traumatic brain injury (%)	1.5	–	1.1	–
Length of hospital stay (days)	6.4	4.5	6.2	3.0
Opioid scripts (12 month presurgery)	3.2	6.8	2.4	5.2
Opioid scripts (12 month postsurgery)	2.1	4.9	2.8	5.1
Age on day of surgery	68.2	12.0	69.5	9.9
Mean postsurgical NDVI	0.527	0.123	0.526	0.121

*Following IDI protocols, all sample sizes have been rounded to the nearest multiple of three.
†Aggregate category used by Statistics New Zealand to describe Middle Eastern, Latin American or African ethnicity.
CHD, coronary heart disease; COPD, chronic obstructive pulmonary disease; IDI, Integrated Data Infrastructure; MELAA, Middle Eastern, Latin American and African; MI, myocardial infarction; NDVI, Normalised Difference Vegetation Index; NZ, New Zealand.

We had no information on participants' presurgical or postsurgical physical activity. Therefore, exposure metrics describe the physical environment that a participant is exposed to, but they do not describe how a participant physically interacts with different environments.

Walkability

We used a previously validated walkability index[27] with three components: number of households per hectare (data source: 2006 New Zealand Census), number of road intersections per square kilometre (data source: Land Information New Zealand) and land-use mix (data source: 2008 New Zealand Land Cover Database V.4.1). In all three cases, we used the version of each data source that was closest to baseline. Land-cover data were available from 2001, 2008 and 2012. However, the classification schemes were not consistent across the 3 years. In addition, when we compared 2008 and 2012 data, we found that the net area of New Zealand that changed from one land class to another was only 0.903%. Therefore, we used 2008 data for our analysis.

Land-use mix is defined as:

$$Land - use\ mix = \frac{\sum_{i=1}^{n} (LC_i * ln(LC_i))}{ln(N)}$$

Where LC_i denotes the proportion of each meshblock that is covered by the ith land-cover type and N denotes the total number of land-cover types. Following Frank *et al*, we standardised household density, intersection density and land-use mix (by subtracting the mean and dividing by the SD), and summed the three standardised scores into a single walkability index.

Greenness

We used two measures of exposure to the natural environment: land-cover data (see above) and the Normalised Difference Vegetation Index (NDVI), which is a greenness index derived from satellite imagery. Specifically, for each year from 2005 to 2016, we used maximum annual NDVI derived from 30m-resolution Landsat imagery that was calculated at the top of the atmosphere, which normalised all atmospheric effects. We standardised NDVI values to make regression coefficients easier to interpret. From these annual values, we calculated mean postsurgical greenness exposure.

Covariates

Using data from the IDI, we controlled for sex, ethnicity and age. In addition, we controlled for neighbourhood deprivation using the New Zealand Deprivation Index (NZDep), which is a well-validated index calculated from nine census variables.[28] NZDep ranges from 1 to 10 with higher values denoting higher levels of social deprivation. Finally, we controlled for eight chronic conditions at the time of surgery: coronary heart disease, gout, chronic obstructive pulmonary disease (COPD), diabetes, cancer, stroke, acute myocardial infarction and traumatic brain injury. We chose to account for these conditions as they are major health outcomes that could affect surgical recovery, and they were predefined by Statistics New Zealand based on hospital-admissions and pharmacy data.[29] Note that we did not have access to data on physical activity, body mass index or diet.

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Statistical analysis

We analysed time-to-death data using a frailty model that included hospital-level random effects. We were particularly careful to account for the hospital where the surgery was performed, because smaller hospitals that may not be able to provide the specialist care of a larger hospital are more likely to be in rural areas that are greener. We evaluated five different functional forms for the survival function (Weibull, exponential, log-logistic, log-normal and gamma) and chose between them using the Akaike information criterion. We analysed the number of post-operative opioid scripts using a mixed negative-binomial regression that included hospital-level random effects.

A backwards-selection procedure was used for all model selection: variables were dropped from the analysis using progressively smaller p value thresholds (final threshold: p<0.1). Insignificant variables can still be confounders,[30] so we systematically re-introduced dropped variables and retained them if the coefficients on variables of interest changed by more than 10%.

To avoid including highly collinear combinations of variables, we estimated ordinary least squares versions of each model (results not shown), which allowed us to calculate variance-inflation factors for each independent variable. If any variable had a variance-inflation factor over two, we dropped it from the regression model. When choosing between two collinear variables, we included the variable with the lowest p value when individually regressed against the dependent variable.

We also conducted stratified analyses to see whether the relationship between the natural environment and health outcomes was the same across different strata of the sample. Analyses were conducted for hip and knee arthroplasty combined as well as for each outcome separately.

RESULTS

Table 1 provides descriptive statistics for our sample.

In the frailty model, specifying the survival function using a Weibull distribution gave the best model fit. Being older, male, European New Zealander or Māori (the indigenous people of New Zealand) were all mortality risk factors (table 2) (The reference ethnic group was Pacific; Asian; Middle Eastern, Latin American and African or other). Similarly, people who received more presurgery

Table 2 Frailty model of time to all-cause mortality (hip and knee: number of participants=14 010, number of observations=149 523; hip: number of participants=7449, number of observations=78 501; knee: number of participants=6558, number of observations=71 022)†. The ethnicity reference group is a composite of all ethnicities other than European NZ or Māori

	Hip and knee		Hip		Knee	
Variable	**HR**	**95% CI**	**HR**	**95% CI**	**HR**	**95% CI**
Age (years)	1.090***	1.086 to 1.094	1.084***	1.078 to 1.089	1.098***	1.091 to 1.105
Female	0.711***	0.667 to 0.758	0.730***	0.670 to 0.796	0.665***	0.604 to 0.732
Ethnicity: European NZ	1.309***	1.151 to 1.490	1.279***	1.063 to 1.538	1.284***	1.072 to 1.537
Ethnicity: Māori	2.137***	1.806 to 2.528	1.910***	1.516 to 2.406	2.286***	1.778 to 2.939
Mean postsurgical NZDep	1.010*	0.998 to 1.023	1.018**	1.002 to 1.035	0.999	0.980 to 1.017
Chronic condition: COPD	1.448***	1.325 to 1.583	1.410***	1.250 to 1.591	1.478***	1.294 to 1.688
Chronic condition: acute MI	1.442***	1.293 to 1.607	1.384***	1.199 to 1.597	1.476***	1.249 to 1.744
Chronic condition: cancer	1.485***	1.357 to 1.625	1.592***	1.417 to 1.790	1.333***	1.157 to 1.536
Chronic condition: stroke	1.567***	1.346 to 1.825	1.702***	1.394 to 2.078	1.385***	1.094 to 1.755
Chronic condition: diabetes	1.306***	1.203 to 1.417	1.278***	1.142 to 1.430	1.342***	1.191 to 1.513
Chronic condition: traumatic brain injury	1.299*	0.994 to 1.697	1.193	0.835 to 1.703	1.452*	0.968 to 2.177
Opioid scripts 12 months presurgery	1.005***	1.004 to 1.006	1.018***	1.014 to 1.022	1.004***	1.002 to 1.006
Mean postsurgical NDVI (standardised)	0.954***	0.922 to 0.987	0.936***	0.895 to 0.979	0.978	0.929 to 1.029
Length of hospital stay	1.034***	1.029 to 1.039	1.030***	1.025 to 1.036	1.052***	1.040 to 1.063
Variance of hospital random effect	0.01404		0.011138		0.006208	
Number of hospitals†	54		51		51	

***p<0.01, **p<0.05, *p<0.1.

†Following IDI protocols, all sample sizes (including the number of hospitals) have been rounded to the nearest multiple of three.

COPD, chronic obstructive pulmonary disease; IDI, Integrated Data Infrastructure; MI, myocardial infarction; NDVI, Normalised Difference Vegetation Index; NZ, New Zealand; NZDep, New Zealand Deprivation Index.

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Table 3 Frailty model of time to all-cause mortality following hip or knee arthroplasty with NDVI quartiles (hip and knee: number of participants=14 010, number of observations=149 523; hip: number of participants=7449, number of observations=78 501; knee: number of participants=6558, number of observations=71 022)†. The ethnicity reference group is a composite of all ethnicities other than European NZ or Māori

	Hip and knee		Hip		Knee	
Variables	HR	95% CI	OR	95% CI	OR	95% CI
Age (years)	1.090***	1.086 to 1.094	1.083***	1.078 to 1.089	1.098***	1.091 to 1.105
Female	0.714***	0.670 to 0.761	0.735***	0.674 to 0.801	0.666***	0.605 to 0.734
Ethnicity: European NZ	1.305***	1.147 to 1.484	1.272**	1.058 to 1.529	1.277***	1.066 to 1.53
Ethnicity: Māori	2.124***	1.796 to 2.513	1.895***	1.504 to 2.386	2.276***	1.771 to 2.926
NZDep	1.012*	1.000 to 1.024	1.021**	1.005 to 1.038	0.998	0.98 to 1.016
Chronic condition: COPD	1.448***	1.325 to 1.583	1.41***	1.249 to 1.591	1.476***	1.292 to 1.686
Chronic condition: acute MI	1.443***	1.295 to 1.608	1.383***	1.199 to 1.596	1.476***	1.249 to 1.744
Chronic condition: cancer	1.489***	1.361 to 1.629	1.602***	1.425 to 1.8	1.33***	1.154 to 1.532
Chronic condition: stroke	1.568***	1.347 to 1.826	1.702***	1.394 to 2.079	1.384***	1.092 to 1.753
Chronic condition: diabetes	1.307***	1.204 to 1.418	1.275***	1.139 to 1.427	1.348***	1.196 to 1.519
Chronic condition: traumatic brain injury	1.300*	0.995 to 1.699	1.194	0.836 to 1.705	1.464*	0.976 to 2.195
Opioid scripts 12 months presurgery	1.005***	1.004 to 1.006	1.018***	1.014 to 1.023	1.004***	1.002 to 1.006
NDVI (standardised) quartile 2	0.933	0.856 to 1.017	0.988	0.881 to 1.107	0.852*	0.747 to 0.971
NDVI (standardised) quartile 3	0.953	0.873 to 1.041	0.926	0.823 to 1.042	0.974	0.854 to 1.111
NDVI (standardised) quartile 4	0.884**	0.804 to 0.971	0.863**	0.762 to 0.978	0.902	0.784 to 1.038
Length of hospital stay	1.034***	1.029 to 1.039	1.03	1.024 to 1.035	1.052***	1.041 to 1.064

***p<0.01, **p<0.05, *p<0.1.
†Following IDI protocols, all sample sizes (including the number of hospitals) have been rounded to the nearest multiple of three.
COPD, chronic obstructive pulmonary disease; IDI, Integrated Data Infrastructure; MI, myocardial infarction; NDVI, Normalised Difference Vegetation Index; NZ, New Zealand; NZDep, New Zealand Deprivation Index.

opioids, or had a longer hospital stay, were at greater risk of mortality. Six chronic conditions were risk factors as was higher neighbourhood deprivation, although this relationship was only significant for hip arthroplasty.

People who lived in greener neighbourhoods (defined as mean postsurgical NDVI) were at lower risk of mortality, although this relationship was only significant in the hip-and-knee arthroplasty and hip-arthroplasty-only models (table 2). To better elucidate the dose-response function linking NDVI and mortality, we re-estimated the hip-and-knee-arthroplasty frailty model splitting NDVI into quartiles (table 3). Only the highest quartile was statistically significant, in the combined and hip-only models, although NDVI remained protective in the second and third quartiles. In the knee-only model, the second quartile of NDVI was protective although only at the 10% level. In addition, the third and fourth quartiles of NDVI did not show a consistent protective effect.

Figure 1 shows the OR for mean lifetime NDVI for different strata of the sample. Stratifying the sample resulted in some loss of significance, due to lower numbers in each stratum. Notably, the protective effect of NDVI was higher for men than women. The protective effect of NDVI was also modestly higher for people who lived in higher socioeconomic status (SES) neighbourhoods (NZDep 1 to 5) compared with lower SES neighbourhoods (NZDep 6 to 10). Similarly, NDVI was somewhat more protective for people who were younger than average (mean age at surgery=68).

In the opioid model (table 4), women, European New Zealanders and people who were prescribed more presurgery opioid prescriptions received significantly more postsurgical opioid scripts in all three time periods with the exception of European New Zealanders in the 24 months postsurgery model (table 4). Those who received a knee arthroplasty (as opposed to a hip arthroplasty) or stayed longer in hospital also received more postsurgical opioids, as did people who had COPD, coronary heart disease or traumatic brain injury. In contrast, older people received fewer opioid prescriptions, although the significance of this relationship varied across the three time periods. Separating opioids into weak and strong was not revealing and reduced the significance of variables of interest (data not shown). Mean postsurgical greenness was associated with significantly fewer postsurgical opioid prescriptions in all three time periods (table 4). Living in a rural area and land cover were not significantly associated with the number of postsurgical opioid prescriptions or time to

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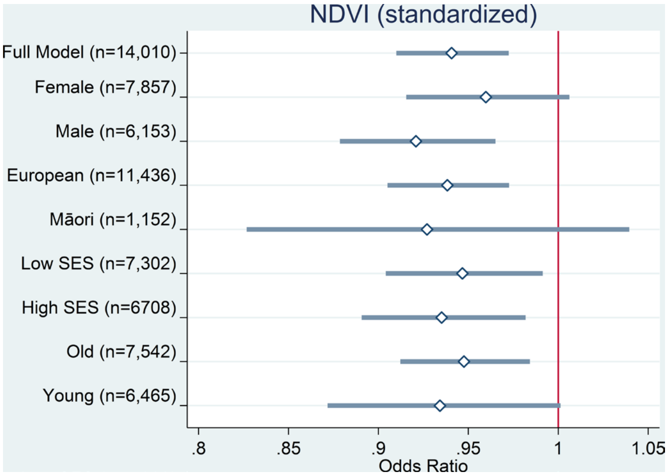

Figure 1 OR plot of standardised mean postsurgical NDVI for time to all-cause mortality following hip or knee arthroplasty (number of participants=14 010, number of observations=149 523).[1] Low/high SES denotes participants whose lifetime NZ deprivation index is above/below average. Old/young denote participants who are older/younger than the sample mean. The ethnicity reference group is a composite of all ethnicities other than European NZ or Māori (figures 1 and 2 were created with the user-written Stata command COEFPLOT). [1]Following IDI protocols, all sample sizes have been rounded to the nearest multiple of three. IDI, Integrated Data Infrastructure; NDVI, Normalised Difference Vegetation Index; NZ, New Zealand; SES, socioeconomic status.

all-cause mortality (data not shown). In addition, walkability was not significantly associated with either opioid use or mortality. For example, the OR on walkability in the 3 month postsurgical opioid model was 1.043 (95% CI 0.966 to 1.127), and the OR in the hip-only frailty model was 1.035 (95% CI 0.971 to 1.104). Even when the analysis was restricted to only-hip or only-knee arthroplasties, the relationship between walkability and mortality or opioid use remained insignificant.

In addition, consistent with the frailty model, NDVI was not significant, when the analysis was restricted to knee-arthroplasty (results not shown). Finally, when we split NDVI into quartiles, none were significant (results not shown).

In the stratified analysis (figure 2), greenness was more protective for men than women, which is consistent with the frailty model.

DISCUSSION

In a cohort of people who received a total hip or knee arthroplasty at a publicly-funded hospital in New Zealand in 2006 or 2007, we found that residents of greener neighbourhoods received fewer postsurgical opioid prescriptions and lived longer, with the strongest results for hip arthroplasty. Our results are consistent with those reported by Ulrich,[10] who found that, after gallbladder surgery, patients recovered faster and took fewer opioids if they were in a room with a view of a natural scene. Our results are also consistent with a previous study,[5] which found that rapid mobilisation following hip or knee arthroplasty was associated with better 2 year survival rates. Finally, results suggests that the benefits of exposure to

Table 4 Mixed negative-binomial model of number of opioid prescriptions 3 months, 12 months and 24 months after hip or knee arthroplasty including a hospital-level random effect (n=14 010)†. The ethnicity reference group is a composite of all ethnicities other than European NZ

	3 months post surgery		12 months post surgery		24 months post surgery	
	HR	95% CI	HR	95% CI	HR	95% CI
Opioid scripts 12 months presurgery	1.083***	1.079 to 1.087	1.136***	1.130 to 1.141	1.147***	1.141 to 1.154
Female	1.124***	1.072 to 1.177	1.177***	1.121 to 1.237	1.195***	1.134 to 1.259
Ethnicity: European NZ	1.247***	1.171 to 1.329	1.121***	1.051 to 1.196	1.01	0.944 to 1.080
Age	0.994***	0.992 to 0.996	0.998	0.996 to 1.001	0.998*	0.995 to 1.000
Mean postsurgical NDVI (standardised)	0.969***	0.947 to 0.992	0.971**	0.947 to 0.995	0.969**	0.944 to 0.994
Knee	1.653***	1.578 to 1.731	1.594***	1.519 to 1.673	1.547***	1.471 to 1.627
COPD	1.219***	1.133 to 1.311	1.272***	1.175 to 1.378	1.374***	1.262 to 1.496
CHD	1.133***	1.057 to 1.214	1.091**	1.012 to 1.175	1.069*	0.988 to 1.157
Traumatic brain Injury	1.197*	0.992 to 1.444	1.335***	1.088 to 1.637	1.448***	1.166 to 1.799
Days in hospital	1.015***	1.009 to 1.022	1.035***	1.027 to 1.043	1.037***	1.029 to 1.045
Variance of hospital random effect	1.164***	1.064 to 1.272	1.072***	1.020 to 1.127	1.071**	1.009 to 1.137

***p<0.01, **p<0.05, *p<0.1.
†Following IDI protocols, all sample sizes have been rounded to the nearest multiple of three.
CHD, coronary heart disease; COPD, chronic obstructive pulmonary disease; IDI, Integrated Data Infrastructure; NDVI, Normalised Difference Vegetation Index; NZ, New Zealand.

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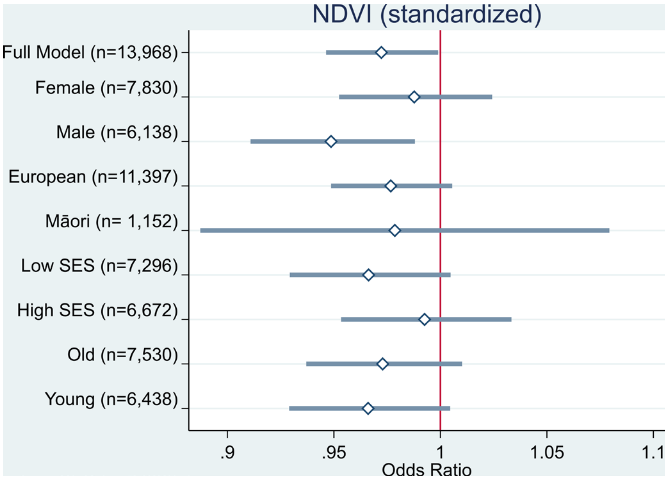

Figure 2 OR plot of standardised mean postsurgical NDVI for number of opioid prescriptions 3 months postsurgery (n=14 010).[1] For definitions and reference groups see figure 1. [1]Following IDI protocols, all sample sizes have been rounded to the nearest multiple of three. IDI, Integrated Data Infrastructure; NDVI, Normalised Difference Vegetation Index; SES, socioeconomic status.

the natural environment extend beyond the immediate postsurgical period.

Greenness was associated with lower postsurgical opioid use, and lower mortality, in people recovering from hip arthroplasty but not those recovering from knee arthroplasty. This may be because knee arthroplasty is a more difficult and painful surgery to recover from[31] (postsurgical opioid use was 65% higher for knee-arthroplasty patients in our sample), and the protective effect of neighbourhood greenness is insufficient to induce a clinically significant increase in postsurgical mobilisation.

There was modest evidence that younger people, and those living in less deprived neighbourhoods, derived greater benefit from exposure to greenness. This may be because younger people are more physically able to engage in outdoor activity, and that greenspace in higher SES neighbourhoods may be better maintained and more appealing because of lower crime.[32]

When we split NDVI into quartiles in the frailty model, we found that only the top quartile was protective at conventional significance levels. This suggests that there may be a minimum threshold below which greenness offers no health benefits. However, it is important to note that NDVI is a coarse measure of overall greenness. It does not reveal which elements of the natural environment provide the greatest health benefits. Identifying the most protective elements would help inform the design of landscapes that are not in the top quartile of NDVI, but nonetheless provide health benefits.

The magnitude of the protective effect of neighbourhood greenness is not trivial. For example, in the 3 months postsurgery model of opioid use, a 2-SD decrease in NDVI is roughly equivalent to the risk of having chronic heart disease at the time of surgery. In the hip-only frailty model, a 2-SD decrease in NDVI is roughly equivalent to the risk of being 2 years older.

Physical activity is likely not the only mechanism linking greenness and improved postsurgical outcomes. For example, exposure to the natural environment can reduce short-term markers of stress such as heart rate, blood pressure and salivary cortisol.[33 34] In turn, stress is a well-documented risk factor for premature mortality[35] and can also trigger opioid cravings.[36] Similarly, exposure to the natural environment is associated with increased social connectivity,[37] and social isolation can increase individual reactivity to opioids[38] as well as being a risk factor for premature mortality.[39] More recently, research suggests that exposure to the natural environment may increase the microbial diversity of the human microbiome,[40] and protect against adverse health outcomes[41] through improved immune function. In addition, improved immune function is associated with improved surgical recovery[42] and better orthopaedic outcomes in elderly patients.[43]

Our study has several limitations. This is an observational study, so we were not able to establish a causal relationship between exposure to the natural environment, opioid use and surgical recovery. In addition, our metrics of exposure to the natural environment were coarse. In particular, meshblock-level NDVI is an imperfect measure of a person's exposure to the natural environment. This is especially true in larger, rural meshblocks, where mean NDVI may not optimally represent a person's residential exposure to the natural environment.

CONCLUSIONS

In a large (n=14 010) cohort of participants who received a hip or knee arthroplasty at a publicly-funded New Zealand hospital in 2006 or 2007, we found that exposure to the natural environment was associated with fewer postsurgical opioid prescriptions, and increased time to all-cause mortality, in hip-arthroplasty patients only. Results suggest that clinicians should consider a patient's home environment when designing postoperative care plans. In particular, clinicians may wish to explicitly incorporate neighbourhood greenspace. When a patient doesn't have access to greenspace, additional support may be warranted to encourage at-home mobilisation.

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