Incidence of malignant lymphoma in adolescents and young adults in the 58 counties of California with varying synthetic turf field density

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ARTICLE INFO

Keywords:
Lymphoma
Crumb rubber
Synthetic turf fields

ABSTRACT

Background: Case reports of cancer among soccer players raised concerns that the crumb rubber infill in synthetic turf fields may cause malignant lymphoma. One prior epidemiologic study on the topic found no association.

Methods: An ecologic evaluation of county-level incidence of lymphomas by race/ethnicity and socioeconomic status for the state of California with data obtained from the National Cancer Institute Surveillance, Epidemiology, and End Results Program. Synthetic turf field density by county was obtained from the Synthetic Turf Council. During 2000–2013, 7214 14- to 30-year-old Californians were diagnosed with malignant lymphoma.

Results: Annual lymphoma county incidence trends were not associated with the county-level synthetic turf field density. None of 20 sub-analyses by race/ethnicity, sex and county median household income indicated a correlation of lymphoma incidence with synthetic turf field density. In California, there was no evidence at the county-level that synthetic turf fields are associated with an increased incidence of lymphoma in adolescents and young adults.

Conclusion: Our findings in the state with the greatest number of such fields and a large, diverse patient population are consistent with those of a prior study observing no association between individual-level exposures to turf fields and cancer incidence. Avoidance of synthetic turf fields for fear of increased cancer risk is not warranted.

1. Background

A University of Washington soccer coach noticed an apparent cluster of young adult soccer players, particularly goalkeepers, who had been diagnosed with lymphoma \cite{1}. The crumb rubber infill in the synthetic turf fields on which they played became the primary suspect since it contains some potentially carcinogenic chemicals such as polycyclic aromatic hydrocarbons \cite{2}. The synthetic turf fields are now the focus of intense toxicology research efforts in California and elsewhere in the United States \cite{3-8}. These are expected to require years to complete, with collection of tire crumb rubber from recycling facilities and installed fields, extensive physical and chemical analysis of the material, and estimation of the nature and duration of exposures to players \cite{9}. Meanwhile, some school systems and park departments have abandoned plans to install synthetic turf fields and playgrounds, and some states have introduced bills to ban such installations \cite{10}.

Recently, the Washington State Department of Health \cite{11} evaluated soccer players in Washington who were diagnosed with cancer during 2002–2015 while 6 to 24 years of age, and compared their cancer incidence with expected age-specific cancer incidence. This study found no evidence for a greater-than-expected increase in the observed numbers of lymphoma or other cancers in the soccer players, regardless of age, intensity of play, or as goalkeepers, who are more contact with crumb rubber. The study found that goalkeepers and outfield players had lymphoma rates that were statistically-significantly lower than expected \cite{11}.

Lymphoma incidence in young Americans varies with race/ethnicity and socioeconomic status \cite{12-17}, Supplementary Fig. S1), factors that were not assessed by the Washington State investigators. They also had to make several assumptions about the number and ages of players, and the upper age limit of 24 years they chose may also have missed diagnoses of cancer that occurred more years after exposure to the fields. Therefore, using data from California, the state with the greatest number of synthetic turf fields, we examined whether the incidence of lymphoma in 14 to 30 year-olds is higher or increasing to a greater extent in regions with higher density of synthetic turf fields.

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https://doi.org/10.1016/j.canep.2018.01.010
Received 12 November 2017; Received in revised form 17 January 2018; Accepted 18 January 2018
Available online 08 February 2018
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2. Methods

2.1. Lymphoma incidence

Race/ethnicity and median family income for each of California’s 58 counties were obtained from the National Cancer Institute Surveillance, Epidemiology and End-Results (SEER) Program [18]. Eligible lymphoma cases were those diagnosed between 14 and 30 years of age with first primary, malignant Hodgkin or non-Hodgkin lymphoma. This age group was chosen to include high school and college age players, allow several years after college for the lymphoma to become clinically detectable, and generally match the age range of players in the original report [1,11]. Hodgkin and non-Hodgkin lymphoma were combined because of their overlapping peak prevalence in the selected age group (Fig. 1) [15] and the mixture of both types of lymphoma in the reported cases [19]. Incidence rates were age-adjusted by the SEER Program at 1-year age intervals to the 2000 U.S. Standard Population [20].

2.2. Synthetic turf field density

The number of synthetic turf fields in each California county as of 2016 was obtained from the Office of Environmental Health Hazard Assessment, California Environmental Protection Agency [21]. All of the fields were outdoors and installed after 1995, but their surface area and specific turf product were not identified. Synthetic turf field density was defined as the number of fields per 100,000 average annual population of 14 to 30 year-olds during the years evaluated. The annual lymphoma incidence was evaluated by year during 2000–2013 (and for two counties explained below, 1975–2013). Also, with the installment of synthetic turf fields during the past decade and reports of field-associated lymphoma dating back to 2009 [1,22], analyses of the associations between synthetic turf field density and lymphoma incidence were conducted with 2009–2013 data. To ensure that the numbers of cancer cases were sufficient in subset analyses, only counties with populations of > 15,000 14 to 30 year-olds were evaluated.

The 58 counties of California were either divided into two or three groups of synthetic turf field density, depending on the parameter evaluated: low or high if the field density was above or below 8.5 synthetic fields per 100,000, respectively; low, intermediate, or high for those having a density of < 4, 4-11, and > 11 synthetic fields per 100,000, respectively (Supplementary Table S1). These criteria were based on gaps in the distribution of the fields by synthetic turf field density that suggested such separations.

2.3. Race/ethnicity and income

For subgroup analyses of race/ethnicity and county median family income, the synthetic turf field densities were divided into two groups and the county median family income below or above $50,000 in 2000 (Supplementary Table S2). Some counties had too small a population to include in specific analyses such as 4 of the 58 counties for correlation assessment of APC and synthetic turf field density. Sub-analyses of race/ethnicity and income required elimination of more counties, such as 20, 21 and 37 counties for Hispanics, Asians and blacks, respectively. In each of these instances, a minimum population of 15,000 of the study group was required.

The two counties with the highest synthetic turf field density, Marin and San Mateo counties, are in the original SEER registry (SEER9, with reliable cancer incidence data back to 1975). They are also in the upper tier of median county family income and hence would be more likely, with a higher expected lymphoma incidence and the greatest synthetic turf field density, to demonstrate a relationship over the longest evaluatable interval of time. Hence, the annual incidence of lymphoma for 1975–2013 was also assessed for these two counties combined, using the SEER9 database [23]. Only whites were evaluable for a race/ethnicity subgroup over the entire 1975–2013 span, since Hispanics and Asians were not identified until 1992 and the black population in these counties was less than 15,000.

2.4. Statistical analysis

Regressions were analyzed for statistical significance with the ANOVA F-test. Average percent change (APC) of incidence was either provided by SEER*Stat [14,23] based on logarithmic values of annual incidence rates or calculated from logarithmic values for data not provided by SEER. Since the APC calculation cannot be applied to zero values, original values of 0 cannot have a discrete logarithm value were assigned a logarithm equivalent of 1 and 1 was added to all other logarithm values.
Table 1

<table>
<thead>
<tr>
<th>Synthetic Field Density</th>
<th>Median Family Annual Income</th>
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<tr>
<td></td>
<td>Low Inter-</td>
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<td>medi-</td>
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<tr>
<td>Classification Criteria:</td>
<td>&lt; 4’</td>
</tr>
<tr>
<td>Number of Counties:</td>
<td>28</td>
</tr>
<tr>
<td>Number Diagnosed with Lymphoma</td>
<td>Non-Hispanic Whites</td>
</tr>
<tr>
<td></td>
<td>Hispanics</td>
</tr>
<tr>
<td></td>
<td>Blacks+</td>
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<tr>
<td></td>
<td>Asians+</td>
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<tr>
<td></td>
<td>All Races/Ethnicities+</td>
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Incidences of Lymphoma per 100,000 Population

| Classification Criteria: | Non-Hispanic Whites | Hispanics | Blacks+ | Asians+ | Total Incidence |
|                         | 6.11 | 7.61 | 7.91 | 6.90 | 7.91 | 7.20 | 7.67 |

* Number of synthetic turf fields per 100,000 population of age 14 to 30 during 2000–2013.
+ 2.8% of the blacks and 1.5% of the Asians also regarded themselves as Hispanic.

3. Results

3.1. Demographics (Table 1)

A total of 7214 Californians were 14 to 30-year-olds when diagnosed with malignant lymphoma during 2000–2013. Of these, 3438 were non-Hispanic white, 2316 were Hispanic, 565 were black (16 were Hispanic black), and 788 were Asian (12 were Hispanic Asian). The incidence of malignant lymphoma varied in the subgroups of synthetic turf field density, race/ethnicity, and median family annual income evaluated from a low of 2.79 to a high of 7.91 per 100,000 age 14–30 population. Fifty-four of the 58 counties in California had a 14- to 30-year-old population of > 15,000 during the years evaluated (14).

3.2. County lymphoma incidence vs. synthetic turf field density (Figs. 2 and 3)

The mean lymphoma incidence was higher in high synthetic turf field density counties than in intermediate density counties and higher in counties with intermediate field density than in those with low field density (Fig. 2). There has been, however, no statistically-significant change in lymphoma incidence in counties in any of the three levels of synthetic turf field density during the 14-year period, whether evaluated by linear, logarithm, power or exponential regressions (Fig. 2, embedded table). The county-level incidence of lymphoma was not positively correlated with synthetic turf field density (Fig. 3), overall or among counties with low or high median family income (Fig. 3, embedded table). None of the race/ethnicity-income subgroups had a lymphoma incidence that was significantly associated with synthetic turf field density (Supplementary Fig. S2).

3.3. Counties with greatest synthetic turf field density and period of evaluation (Fig. 4)

The two California counties with the greatest synthetic turf field densities have reliable cancer incidence data that date back to 1975: Marin and San Mateo counties with 29.8 and 29.5 fields per 100,000 population of 14 to 30-year-olds, respectively. The annual lymphoma incidence in these counties over the 39 years from 1975 to 2013 did not change, either overall or among males, females, or whites, during the last 18 years when their synthetic fields were installed (Fig. 4).

3.4. Additional analyses

For the last 5 years of data, 2009 to 2013, there was no difference by race/ethnicity and county-level median household income for two levels of synthetic turf field density (Supplementary Fig. S3). The following additional analyses did not change the findings presented above: expanding the interval assessed for those analyses performed on 2009–2013 to 2000–2013; including counties with < 15,000 population; varying the lower and upper limits of the age range to 10 or 13 and 24, respectively; varying the synthetic turf field density groupings (≤ 1, 1–7, > 7); and varying the median family income level categories (< $45,000, $45,000–$50,000, > $50,000; < $35,000, $35,000–$50,000, > $50,000; < $35,000, $35,000–$70,000, > $70,000), and testing for statistical significance with exponential, logarithmic or power functions of lymphoma incidence versus synthetic turf field density.

4. Discussion

As expected, regions with higher synthetic turf field density did have a higher lymphoma incidence since lymphoma incidence is positively correlated with socioeconomic status and such regions are able to install more synthetic turf fields. In all subgroups analyzed for combinations of race/ethnicity, county median household income and synthetic turf field density, we found no statistically-significant associations at the county-level between the incidence of lymphoma and synthetic turf field density, or in incidence trends over time as more such fields were installed.

The two California counties with the greatest synthetic turf field densities not only have reliable cancer incidence data since 1975, they also have been in the highest tier of county median family income since then. Over a 39-year interval during the last 18 years of which their synthetic turf fields were installed, there is no evidence of an increase overall, in males or females, or in whites. That males have not been affected has additional significance since, in general, they have used the fields more than females.

In total, none of 20 sub-analyses of race/ethnicity, sex and county-level median household income analyzed indicated a correlation of lymphoma incidence with synthetic turf field density. These overall epidemiologic findings are consistent with studies that have measured levels of carcinogens released from crumb rubber from synthetic turf fields and interpreted their data to indicate negligible cancer risk to children or older persons [24,25]. A study conducted in Italy concluded that the risk of cancer from the measured, known carcinogens in artificial-turf playing fields was on the order of one in a million after 30 years of intense playing on such fields [26]. In another study conducted in the Netherlands, there was no evidence for an increase in the urine of l-hydroxylyprine in 6 of 7 soccer players who exercised and before his urine samples contained the hydrocarbon.

Patients with cancer treated with carcinogenic chemotherapy agents have later developed non-Hodgkin lymphoma [28], but neither...
Hodgkin nor non-Hodgkin lymphoma have had definitive environmental chemical carcinogens identified despite years of study [29,30]. Asbestos, butadiene, and organic solvents had been suspected in the past but ultimately shown not to be causes of lymphoma [31–34]. A recent meta-analysis conducted in China of 31 studies suggests that higher external exposure to dioxin may increase the risk of non-Hodgkin lymphoma [35]. Also, benzene has been implicated as a non-Hodgkin lymphomagen [36–40]. More accepted as environmental risk

![Fig. 2. Annual Incidence and Average Percent Change (APC) of Malignant Lymphoma in California, Age 14–30, 2000–2013, by County Density of Synthetic Turf Fields.](image)
factors for non-Hodgkin lymphoma than chemical carcinogens are immunosuppressive vectors such as Epstein-Barr virus (EBV), human immunodeficiency virus [41], and hepatitis B virus [2]. It is also unclear how carcinogens of crumb rubber bound up within the vulcanized rubber matrix can be absorbed in either the gastrointestinal tract or pulmonary airways, as suggested by the Netherlands study.

Finally, lymphoma is the most common malignancies in 14- to 30-year-old Americans [42], with 1 in every 4 to 5 persons diagnosed with invasive cancer in the age group to have Hodgkin or non-Hodgkin lymphoma [Fig. 1]. Thus lymphoma would be expected to be the cancer observed most frequently in high school and college age soccer players as an expected occurrence and not an unusual finding that needed explanation [19]. If the rate were higher than expected would be concerning but is not apparent in our study and found to be lower than expected in the Washington state study.

Although we combined non-Hodgkin and Hodgkin lymphoma, they are biologically and etiologically different and may be environmentally influenced such as EBV-associated Burkitt and Hodgkin lymphomas [43]. There were, however, a similar numbers of Hodgkin and non-Hodgkin lymphoma cases in the original report, as would have been naturally expected (Fig. 1), and no evidence for an association of either with synthetic field exposure [11].

The main limitation of this study is its sensitivity to detect lymphoma incidence differences at the population level of those who use the synthetic turf fields and those who do not [44]. According to the Washington State, approximately 25% of their 15-year-olds played soccer [11]. Given that California probably has a higher overall synthetic field density and a higher proportion of youth playing soccer, our
An ecologic study may have been less likely to miss effects that occur at the individual level.

Without historical data, the synthetic turf field density was based on available information in 2017 and thus the density distribution likely differed during early years of evaluated in this study. However, it is likely that higher SES counties would have installed fields earlier, overcoming some of this limitation.

Another potential constraint is that our era of assessment of carcinogen exposure may not have sufficiently antedated the onset of cases reported to be linked to the fields. We doubt that the lag period for carcinogenesis is a major factor since most of the linked cases that met the Washington state case selection criteria were in 2007–2015 and the earliest was in 2002 [11]. Our assessment intervals of lymphoma incidence trends date back to 1975, 1992 and 2000, and for the counties with the greatest density of synthetic fields, back to 1992. Also, evaluating lymphoma incidence in 14 to 30 year-olds allowed for more lag time from the onset of exposure to potential environmental carcinogens to the development of clinical cancer than the 6 to 24 year age range used in the Washington state study [11], and it also corresponds more closely to the natural incidence peak in the older age range (Fig. 1) [19].

Despite the limitations, we offer our county-level analysis in the state with the most number, and areas with the highest densities, of synthetic turf fields with crumb rubber as preliminary evidence for the absence of a strong lymphomagenic effect associated with the suspect fields. Synthetic turf fields are more likely in metropolitan areas (as shown in the California map of the fields in Supplementary Fig. S4), in regions of higher socioeconomic status that can afford such fields, and where local weather favors synthetic fields over natural grass due to rain and freezing temperatures. Thus, the rate of lymphoma should be higher in adolescents and young adults who live near synthetic turf fields because the socioeconomic, metropolitan, and climate topography are consistent with the race/ethnicity and socioeconomic status that is more likely to have lymphoma, as we observed.

The cancer risk of physical inactivity should also be considered. Regular physical activity has been clearly demonstrated to prevent cancer, as well as cardiovascular disease, hypertension diabetes, metabolic syndrome, and other chronic illnesses [45]. Lack of physical activity during adolescence increases the incidence of cancer in later adult life [46]. Lack of access to facilities that allow exercise year round could thereby potentially increase the incidence of cancer. Indeed, the Washington State study found that soccer players of all ages had a statistically-significantly lower incidence of all types of cancer, including non-Hodgkin lymphoma, Hodgkin lymphoma and leukemia, compared to age-matched data from their statewide registry. In fact, for field players the observed:expected ratios were all < 0.10 and the upper limits of the 95% confidence intervals were all < 0.20. For goalkeepers, the corresponding values were 0.25 and 0.75.

5. Conclusion

Higher rates of lymphoma incidence in regions with synthetic turf fields generally are explained by the age range, race/ethnicity

![Fig. 4. Annual Incidence of Malignant Lymphoma in the Two California Counties with the Greatest Densities of Synthetic Turf Field with Crumb Rubber (Marin and San Mateo), 1975–2013. Only the evaluable race/ethnicity (white) is shown (lowest panel), as explained in Methods. Data Source: SEER9 regions [23]](https://example.com/fig4)
distribution, and socioeconomic status as measured by family income assignable to counties that have such fields. County-level ecological evidence mitigates against a strong lymphomagenic effect of synthetic turf fields, and supports the Washington State and Netherlands studies.

Because regular physical activity during adolescence and early adulthood early adulthood helps prevent cancer later in life, restricting use or availability of all-weather year-round synthetic fields and thereby potentially reducing exercise could, in the long run, actually increase cancer incidence, as well as cardiovascular disease and other chronic illnesses. Therefore, it is important to consider the results of our and ongoing studies before the use and development of synthetic turf fields and playgrounds, which promote physical activity, are blocked, prevented or precluded because of cancer concerns.

Further studies assessing individual-level exposures among soccer players are needed, most desirably a case-control analysis. Until then, however, physical activity should be encouraged and promoted by year-round, weather-resistant fields. As concluded and recommended by the State of Washington, “no specific field or geographic problem is problematic in terms of soccer players getting cancer” and “persons who enjoy soccer should continue to play irrespective of the type of field surface” [11].

Conflict of interest

This work was self-funded by the authors, who have no known financial conflicts of interest with the content of this report. Specifically, neither Dr. Bleyer nor Dr. Keegan have any known perceived or real conflicts of interest with the industry, other businesses, other research efforts, or health care organizations who have, or may have, at financial or related vested interest in the products studied in this report. We also know of no conflicts of interest that Dr. Crouch, cited above, has with the research conducted for this report.

Authorship contributions

Both authors, Archie Bleyer and Theresa Keegan provided 1) substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; 2) drafting the article or revising it critically for important intellectual content; and 3) final approval of the version the manuscript submitted herein.

Acknowledgments

The authors wish to recognize the advice of Edmund Crouch, PhD, Statistician, and Laura C. Green, PhD, DABT, President & Senior Toxicologist, Green Toxicology LLC. Dr. Crouch was invaluable in assisting with the statistical analyses and presentation of data.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.canep.2018.01.010.

References


