Weather, Chinook, and Stroke Occurrence

Thalia S. Field; Michael D. Hill, MD, FRCPC

Background—Changes in weather and season have been linked to stroke occurrence. However, the association has been inconsistent across stroke types. Calgary is a city in the Chinook belt and is subject to high variability in weather conditions.

Methods—We obtained hourly weather data over a 5-year period from 1996 to 2000; Chinook events were identified according to the accepted definition. We reviewed administrative data to determine stroke occurrence and defined stroke types to maximize specificity of diagnosis. To examine the hypothesis that weather affected the number of strokes occurring in a given day, we compared average daily stroke occurrence on Chinook days and non-Chinook days; we compared mean daily temperature, relative humidity, barometric pressure, and wind speed by the number of strokes occurring on any given day.

Results—Annual variation in stroke frequency was observed. No seasonal, monthly, or weekly variation in overall stroke occurrence or occurrence by type was evident. No relationship with changes in weather parameters was observed.

Conclusions—We found no association between weather changes and stroke occurrence. A cause-and-effect relationship between weather and stroke occurrence is dubious because of a lack of consistency across studies. (Stroke. 2002;33:1751-1758.)

Key Words: epidemiology ■ hemorrhage ■ incidence ■ occurrence ■ stroke ■ weather

Observational studies have linked stroke onset to changes in meteorologic parameters. Increased morbidity and mortality due to ischemic stroke, subarachnoid hemorrhage (SAH), and intracerebral hemorrhage (ICH) have been linked to cooler temperatures1–4 and winter months.5–7 An inverse relationship between stroke mortality and temperature has been presented using American data.4 Studies examining stroke incidence or occurrence have also been inconsistent57–13; to date, no type has been consistently pinpointed as responsive to changes in weather or season from area to area, suggesting that the reported positive associations were confounded by other variables such as cultural or genetic factors. Still, possible biological mechanisms for an apparent seasonal variation and temperature relationship to stroke incidence rates include an increased rate of influenza and respiratory infection morbidity during the winter time,4 increased plasma fibrinogen and blood viscosity,2 vasoconstriction and increased blood pressure at colder temperatures,14 and circannual variation in cortisol levels.8 Although there has been investigation into the sensitivity of stroke onset to temperature changes, as well as the circannual pattern of stroke, the sensitivity of stroke to other meteorologic parameters, such as wind speed, has not been examined extensively. In addition, few if any negative studies regarding weather and stroke incidence have been published, suggesting that if there is no true association, publication bias may be present.15,16

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Calgary is an ideal center for an examination of the effects of weather changes on stroke occurrence because of its location in the so-called Chinook belt. The Chinook wind of southern Alberta belongs to a family of warm winter mountain winds, including the föhn winds of Southern Europe, the Zonda in Argentina and the NorthWesters in New Zealand, that occur in many locations where long mountain ranges lie more or less perpendicular to the prevailing wind.17 So-called föhn illness has been part of Swiss vocabulary for many generations; Ficker and de Rudder’s documentation in 1948 of the perceived ill effects of the föhn included headaches, nausea, insomnia, and aggravated rheumatism.18 More recently, föhn winds in Italy, Germany, and Bermuda have been associated with irritability, heart problems, and worsening asthma.19,20 Chinook winds in particular have recently been linked to migraine onset.21 Still, not all studies have found a detrimental association between föhn and health conditions.16,17

It has been postulated that deleterious health effects in relation to the föhn are linked to an increased concentration of positive ions in the air. The rapid flow of great volumes of air over a landmass may lead to electron stripping, and the resultant reactive positive ions can catalyze reactions leading to the formation of bioactive compounds such as seroto-
Positive atmospheric ion concentrations increase sharply once Chinook winds reach a velocity in excess of 38 km/h. Outdoor concentrations of positive ions are significantly lower than those used in ion-effect studies. Still, in the case of a very windy and dusty Chinook, winds may act as an aggravating factor for stroke, mediated by serotonin, which is known to increase platelet aggregability.

We undertook to examine the relationship between stroke and the weather in Calgary.

**Methods**

**Patient Data Analysis**

The Calgary Health Region serves a population of one million people and provides tertiary care to all of southern Alberta. Administration is coordinated such that hospital discharge data on all patients admitted to Calgary hospitals is amassed centrally. Administrative data from a 5-year period beginning January 1, 1996, and ending December 31, 2000, was examined. All patients with a discharge diagnosis code (International Classification of Diseases, 9th Revision—Clinical Modification [ICD-9-CM]) of 430, 431, 433, 434, or 436 in the first diagnosis position were included. The first diagnosis position was chosen to increase the probability that the patient had suffered a stroke on the date of admission; for example, patients who had suffered a stroke in recent weeks but were admitted to rehabilitation facilities within the hospital were excluded using this approach. Date of admission, date of inpatient discharge, date of birth, gender, and first 5 ICD-9-CM diagnoses were recorded.

Because we were attempting to examine a biological association, we chose to further define stroke types to maximize specificity. Acute ischemic stroke (AIS) was defined by codes 434 or 436 to maximize specificity with known loss of sensitivity (specific AIS definition). We also secondarily considered the definition of AIS when code 433 was included (sensitive AIS definition). ICH was defined by code 431 and SAH by code 430. These choices are supported by the literature.

**Weather Analysis**

Hourly and daily meteorologic measurements were purchased from the Calgary branch of Environment Canada for the years 1996 to 2000. The parameters measured were hourly dry bulb temperature (in 0.1°C), hourly wind direction (in increments of 10 degrees), hourly barometric pressure (in 0.1 mm Hg), hourly relative humidity (in percentages), daily precipitation (in 0.1 mm), and daily normal temperatures (in 0.1°C). These parameters were recorded from Calgary International Airport.

A Chinook was defined according to Nkemdirim’s description. Chinooks occur during the winter months and are characterized by westerly surface winds blowing from south-southwest to west-northwest (225° to 315° measured clockwise from true north) inclusive, a wind speed stronger than 4.5 ms⁻¹ (16.4 km/h) and “gusty,” a sharp upward revision of air temperature with the eventual mean daily value exceeding the normal for the day, a marked drop in relative humidity, and both the increase of air temperature and the drop in relative humidity corresponding perfectly to the western wind gusts.

The magnitude of increase in temperature and decrease in humidity during a Chinook event cannot be quantified because of wide variations in Chinook intensity. Chinooks are characterized by a nearly vertical increase in temperature and decrease in humidity from “background” levels during which shifts in wind direction to “Chinook mode” normally correspond. During a Chinook, temperature and relative humidity plateau until expiration of the event, marked by a “jump” down to background levels of temperature and relative humidity (L.C. Nkemdirim, PhD, personal correspondence, July 25, 2001) (Figure 1).

To define whether a Chinook was present for a given day, all days from October to March inclusive during which the criteria for Chinook wind speed and wind directions were met simultaneously were examined. On each day a graph of hourly wind speed, wind direction, temperature, and relative humidity was examined to determine whether a significant rise in temperature and corresponding significant drop in relative humidity adhering to Chinook criteria were present.

A Chinook day was defined as a calendar day in which a Chinook was present. Pre-Chinook and post-Chinook days were defined as calendar days possessing non-Chinook weather conditions immediately preceding/following a Chinook day.

**Statistical Analysis**

To examine trends in administrative data, the unit of analysis was the number of strokes occurring per day. This was chosen because we reasoned that if weather had an impact on stroke occurrence, more strokes would occur on any given day with particular weather conditions. The average number of strokes per day of each type was examined by day, week, month, year, and season. Seasons were defined as follows: winter (December through February), spring (March through May), summer (June through August), and autumn (September through November). A one-way ANOVA model for each stroke type was used to test the
hypothesis that the average number of strokes per day varied by week, month, season, or year. Daily variation was assessed with summary statistics. Because the number of strokes per day assumed an approximately normal distribution, an unpaired Student t test was used to test the hypothesis that the number of strokes of each type on Chinook days was greater than on non-Chinook days; the same approach was taken for pre- and post-Chinook days. The average temperature, wind speed, relative humidity, barometric pressure, and total daily precipitation were compared, grouped by the number of strokes per day using one-way ANOVA. This was repeated for all stroke types. All statistical analyses were performed using STATA 6.0 (Stata).

Results

Circannual Analysis

Over the 5 years from 1996 to 2000 (1827 days), 3075 strokes were observed including code 433 (sensitive algorithm). The mean age was 69.5 years (SD 14.1), and 53.6% of patients were male. A breakdown by stroke type is shown in Table 1. There was statistical evidence of variation in stroke occurrence on an annual basis but no significant variation by season, month, or week. This was also true for stroke types.
More total strokes occurred during 1999 compared with other years, but this was not due to a particular increase in a stroke type. Daily variation occurred with a range of zero to eight strokes occurring in a single day.

Weather Analysis
Of the 1827 days observed, 912 of these occurred during the “Chinook season,” which is between the months of October and March inclusive. One hundred eighty-two Chinook days were identified during this period from 1996 to 2000. The number of Chinook days per year ranged from 34 to 39 (mean 36.4 Chinooks per year). The accepted mean number of Chinook days over time is 50 per year (SD 16). No relationship between the number of strokes of any type or as a whole could be demonstrated between Chinook days, pre-Chinook days, or post-Chinook days (Table 2). Similarly, no relationship was demonstrable between the number of strokes occurring on a given day and mean temperature, barometric pressure, mean wind speed, maximum wind speed, and relative humidity (Figures 3 and 4).

Discussion
We found neither a seasonal nor a monthly variation of stroke occurrence; nor did we find a correlation between meteorologic parameters, including Chinook events, and stroke occurrence.

Table 2. Lack of Relationship Between Chinook Onset and Number of Strokes per Day

<table>
<thead>
<tr>
<th>Stroke Grouping</th>
<th>Day Category</th>
<th>Mean (Strokes/Day)</th>
<th>Chinook/Pre-Chinook/Post-Chinook Day</th>
<th>Non-Chinook/Pre-Chinook/Post-Chinook Day</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>All stroke*</td>
<td>Chinook day</td>
<td>1.70</td>
<td>1.67</td>
<td>0.67</td>
<td></td>
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<tr>
<td></td>
<td>Pre-Chinook day</td>
<td>1.73</td>
<td>1.65</td>
<td>0.20</td>
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<tr>
<td></td>
<td>Post-Chinook day</td>
<td>1.68</td>
<td>1.69</td>
<td>0.86</td>
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<tr>
<td>All stroke†</td>
<td>Chinook day</td>
<td>1.04</td>
<td>1.06</td>
<td>0.70</td>
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</tr>
<tr>
<td></td>
<td>Pre-Chinook day</td>
<td>1.07</td>
<td>1.03</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Chinook day</td>
<td>1.04</td>
<td>1.06</td>
<td>0.67</td>
<td></td>
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<tr>
<td>AIS</td>
<td>Chinook day</td>
<td>1.16</td>
<td>1.12</td>
<td>0.51</td>
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<td></td>
<td>Pre-Chinook day</td>
<td>1.16</td>
<td>1.12</td>
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<td></td>
<td>Post-Chinook day</td>
<td>1.15</td>
<td>1.13</td>
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<td>0.29</td>
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<td></td>
<td>Pre-Chinook day</td>
<td>0.31</td>
<td>0.30</td>
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</tr>
<tr>
<td></td>
<td>Post-Chinook day</td>
<td>0.29</td>
<td>0.32</td>
<td>0.14</td>
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<tr>
<td>SAH</td>
<td>Chinook day</td>
<td>0.25</td>
<td>0.22</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-Chinook day</td>
<td>0.25</td>
<td>0.22</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Chinook day</td>
<td>0.24</td>
<td>0.23</td>
<td>0.58</td>
<td></td>
</tr>
</tbody>
</table>

*Sensitive definition.
†Specific definition.

Figure 3. Variation in daily mean temperature, barometric pressure, relative humidity, and wind speed by number of strokes in a day (sensitive algorithm). Shown are box-whisker plots of mean weather parameter (y axis) by number of strokes in a given day (x axis) demonstrating that greater or lesser numbers of strokes per day are not related to temperature, barometric pressure, relative humidity, or wind speed. Mean-temp indicates mean daily temperature (°C); meankpa, mean daily atmospheric pressure (kPa); meanwspd, mean daily wind speed (m/s); and meanhum, mean daily humidity (% saturation).
The literature on stroke and the weather suggests inconsistency in the relationship among stroke types and meteorologic parameters. Several studies have reported a circannual pattern of ICH occurrence, as well as a responsiveness of ICH to changes in meteorologic parameters. Jakovljević et al using ICD-9 codes and a national stroke register found that the prevalence of ICH increased during winter months. Similarly, Shinkawa et al found that ICH occurrence exhibited significant seasonal variation, with ICH being negatively correlated with mean ambient temperature. Chen et al found that the occurrence of ICH was approximately twice as great on cooler days (daily mean temperature <17.3°C) than on warmer days (>27.3°C), Biller et al found that the rate of referral for ICH decreased significantly during warm weather and rainy weather, and in a population-based study Feigin et al found that mild ambient temperature was a predictor of ICH. However, Rothwell et al found that no seasonal trend for ICH occurrence existed, although incidence of primary ICH increased at low temperatures. A population-based study by Sobel et al found no correlation between hemorrhage and temperature, whereas Nyquist et al found no increase in ICH occurrence during the winter months.

Evidence supporting a seasonal pattern of SAH occurrence is also inconsistent. Nyquist et al found a significant increase in SAH during the winter months; however, this pattern was not confirmed by previous studies. Sobel et al found no correlation between rates of hemorrhage and temperature, whereas Nyquist et al found no increase in ICH occurrence during the winter months.

Reports of the effects of weather and seasonality on AIS occurrence have also been variable. This may be due in part to the various definitions of AIS put forth by the respective authors. The inclusion of transient ischemic attack (code 435) as part of the definition of ischemic stroke may have confounded reported associations as it has also been suggested that transient ischemic attack has a seasonal variability different from ischemic stroke. Shinkawa et al reported a significant seasonality in occurrence of cerebral infarction, with a negative correlation occurring between infarction rate and temperature. Diagnosis of stroke type was determined by “detailed histories, neurological examination, ancillary diag-nostic procedures,” and autopsy when possible. Thrombosis and embolism were included under the definition of cerebral infarction. Jakovljević et al also found that AIS prevalence (defined by ICD-9 codes 432 to 436) increased during the winter months, and Feigin et al reported that low ambient temperature and mean air pressure were the most important predictors of AIS occurrence; stroke was defined by clinical, radiological, and if available postmortem data. However, Rothwell et al and Chen et al used similar clinical definitions of stroke and found no significant relation between the incidence of AIS and temperature.

Although our data suggest that there is no significant seasonal variation in stroke occurrence or a relationship between changes in weather and stroke occurrence, this does not necessarily suggest that weather or seasonality do not have an effect on stroke outcome. Lanska and Hoffman found that stroke mortality increased during the winter months and was closely associated with seasonal variation in respiratory infection rates. A seasonal variation in fatal stroke has also been found in Italy and Taiwan.

Previous studies examining seasonal patterns of stroke occurrence as well as the relationship between stroke occurrence and mortality and changes in the weather were conducted in disparate areas of the world. It is possible that these studies were confounded by unmeasured factors such as culture, environmental exposures such as cigarette smoking, and ethnogenetic factors. In a country with increased snowfall during the winter, for example, increased stroke rates during the winter may be analogous to increased sudden death due to coronary disease after shoveling snow. Ethnic differences may also account for discrepancies in stroke occurrence from location to location. For example, ICH rates among Asians are higher than among whites.

Because Canada has a cold winter climate, the population tends to stay indoors in climate-controlled conditions. If exposure to components of weather such as temperature and humidity has a dose-response effect, this may have limited the power of this study to demonstrate a link between weather and stroke occurrence. However, other parameters such as barometric pressure remain the same indoors and out and would not be susceptible to such an effect.

We found no significant associations between Chinook events, an extreme of weather variability, and stroke rates. The relationship between Chinook events and cerebrovascular illness has not been examined previously. However, Cooke et al defining a Chinook event as an increase in temperature greater than 3°C in 1 hour accompanied by wind >15 km/h in the direction of south-southwest to west-northwest, found a significant association between increased migraine onset and high-wind Chinook days as well as pre-Chinook days. The mechanism by which Chinook events may cause migraine is undefined.

Publication bias may also explain the apparent inconsistencies in weather data and stroke. Because negative studies tend not to be published, the preponderance of published data supports some kind of association between weather and stroke.

Our analysis has limitations. We assumed that our data were comprehensive because we believe that almost all
patients with stroke are admitted to the hospital in Calgary. Data from Britain,36,37 the use of thrombolysis for stroke in Calgary, and the centralization of stroke services in Calgary38 led us to this belief. However, we have no community data from Calgary to support this claim. The relatively higher proportion of ICHs and subarachnoid hemorrhages in our data compared with those found by the Oxfordshire Community Stroke Project39 data suggest that our data (from 3 adult hospitals) represent a hospital-based admission pattern. Mild strokes that were not admitted to the hospital would not have been included in our data.

We also assumed that the day of admission was the same day as the day of stroke onset. Both the literature and Calgary data support this assumption.40–42 In Calgary, among admitted patients over a 3-month period, the average time from onset to admission was 6.5 hours (SD 9.7 hours).

Because administrative data were used to determine rates of stroke occurrence, we considered both first-ever and recurrent strokes. Although several authors have determined the sensitivity and specificity for stroke diagnosis on the basis of hospital discharge abstracts, prospective identification of cases and the sole inclusion of first-ever strokes would have been ideal. Therefore, the use of administrative data may have increased the “noise” in the data such that an association between weather and stroke was missed. We only examined 5 years’ worth of data. There may be trends in stroke occurrence that occur over long periods of time that are thus not detectable given the resolution of the data. This study examined stroke occurrence and not stroke incidence. It is possible that incident strokes may be weather- or season-sensitive, whereas recurrent strokes are not.

Additionally, we examined the number of stroke occurrences per day and were not able to examine the exact time of onset of stroke. Recent evidence confirms a circadian pattern to ischemic stroke onset.43 However, if a true association with weather existed, one would expect patterns to emerge over the longer periods that we examined.

In summary, we found no association between stroke and changes in the weather. Previous studies have shown a lack of consistency of effect and were potentially biased by unmeasured confounding variables. We posit that there is no relationship between stroke occurrence and the weather.

Acknowledgments

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Stroke mortality increases during the winter months.1–3 This pattern may reflect a number of factors, including an increase in stroke incidence, an increase in case fatality related to secondary causes such as respiratory disease,2 or variation in incidence of risk factors1 during periods of cold temperature. Several studies have suggested that there is an increase in ischemic4–8 and hemorrhagic5,9–11 stroke incidence during the cooler months of the year, while others have found the number of ischemic strokes to increase during the spring or summer months.9,11 One community-based study12 found no seasonal effect on ischemic stroke incidence, as did some hospital-based series.10,14,15 The influence of season on subarachnoid hemorrhage (SAH) incidence is also not clear, with some studies13,16 finding an increase in winter and others5,11 finding no change during the year.

Possible reasons for seasonal variations in ischemic stroke incidence include the effect of ambient temperature on blood pressure (elevated during winter months), sympathetic activity, altered blood viscosity, blood clotting time, and serum fibrinogen levels.1,4,17 The effect of cold weather and in particular abrupt temperature changes and temperature extremes on blood pressure may explain an increase incidence of cerebral hemorrhage and SAH during winter months. But ambient temperature changes are only some of the proposed mechanisms by which the weather might precipitate stroke. A number of investigators have undertaken more detailed analysis of specific meteorological factors such as humidity, barometric pressure, precipitation, wind, and solar and geomagnetic activity,17 again with inconsistent findings.5,10,15,16,18

In this issue of Stroke, Field and Hill report the effect of season and the Chinook on hospital-based stroke incidence in Calgary, Canada. Chinook is the local name given to a peculiar weather pattern found in a number of regions of the world. Warm mountain winds in an area with long mountain ranges lying perpendicular to the wind result in a sudden increase in temperature and concomitant decrease in humidity. The onset of a Chinook weather pattern has been associated with a number of nonspecific medical complaints and migraine.19 Field and Hill retrospectively ascertained all stroke admissions to hospital in Calgary over 5 years using ICD-9-CM codes for stroke by type and subtype and then compared average daily stroke admissions on Chinook and non-Chinook days. Neither the Chinook weather pattern nor season was associated with a change in the number of stroke admissions. There are a number of criticisms of their study, however. Not only is it retrospective and therefore open to inaccuracies in stroke diagnosis and case ascertainment, but it is also not community-based. Despite the authors’ assertion that most stroke patients are admitted to hospital in their region, there is no data to support this claim. As a result, patients with very severe strokes who died prior to admission or very mild strokes who stayed at home may have been missed. The authors included first-ever-in-a-lifetime and recurrent strokes. Recurrent strokes are often difficult to miss. The authors included first-ever-in-a-lifetime and recurrent strokes. The authors included first-ever-in-a-lifetime and recurrent strokes. The authors included first-ever-in-a-lifetime and recurrent strokes. The authors included first-ever-in-a-lifetime and recurrent strokes. The authors included first-ever-in-a-lifetime and recurrent strokes. The authors included first-ever-in-a-lifetime and recurrent strokes. The authors included first-ever-in-a-lifetime and recurrent strokes. The authors included first-ever-in-a-lifetime and recurrent strokes.
best possible measurement of stroke incidence is essential. Therefore, the starting point for assessing the impact of the weather is a comparable community-based incidence study,\textsuperscript{20} with complete case ascertainment of first-ever-in-a-lifetime stroke, accurate differentiation of stroke pathological type and subtype, and whole years of data measured to detect the possible influence of seasonal variation. But community-based studies that have fulfilled these requirements\textsuperscript{21} have also produced contradictory findings of the effect of the weather on stroke incidence,\textsuperscript{6,7,12,13} and there must be other reasons for the lack of consistent findings.

(2) The effect of meteorologic changes on human physiology and the interaction with accepted stroke risk factors is likely to be complex, and the role of factors such as barometric pressure change, humidity, and solar activity is difficult to assess. Whereas it is easy to understand and possibly to measure the impact that a sudden drop in temperature may have on blood pressure and therefore cerebral hemorrhage and aneurysmal SAH incidence, it is far more difficult to measure and predict the time needed to see the result of a similar change in serum fibrinogen levels caused by a change in, for instance, barometric pressure or even temperature. Some studies\textsuperscript{15,18} investigating the influence of factors other than temperature, including that of Field and Hill, have assessed stroke incidence within 1 or 2 days of the weather change being investigated and might have missed longer-term effects of the weather change. Admittedly, measuring the influence on stroke occurrence days or weeks after a specific weather change would be exceptionally difficult.

(3) There may be secondary effects of the weather change such as increases in infections, behavioral changes such as an increase in alcohol consumption, and dietary changes or even use of fuels containing toxins that might influence stroke onset.

(4) Population differences and differences between areas with extreme and mild weather conditions and fluctuations\textsuperscript{14} may add to conflicting results.\textsuperscript{6,15}

In summary, the effect of weather changes and season on stroke incidence is far from clear. A systematic review of the literature and further community-based studies in populations living in regions with a wide range of climatic conditions are needed to determine if and how the weather influences stroke incidence.

Myles D. Connor, FCP(SA), FCP(Neurology)(SA)
Department of Neurology
Faculty of Health Sciences

University of the Witwatersrand
Johannesburg, South Africa

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