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Nocturnal Penile Tumescence and Rigidity Testing in Bicycling Patrol Officers

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Abstract

A health assessment study was conducted in response to complaints of groin numbness in a bicycling police unit. Seventeen male cyclists were compared with 5 nonbiking men. The cyclists rode an average of 5.4 hours per day, and 91% indicated they experienced groin numbness on occasion. Each man wore the RigiScan Plus Rigidity Assessment System for one normal sleep session. Pressure measurements were also taken between the cyclist and the bicycle saddle. The percentage of sleep sessions that recorded an erectile event was significantly lower in the cyclists than it was in noncyclists (cyclists 27.1%; noncyclists 42.8%; $P = .008$). This duration percentage is negatively correlated with average hours a day that cyclists rode their bikes ($r = -.41$; $P = .05$), the number of days a week they rode ($r = -.55$; $P = .009$), and the average pressure exerted on the nose of the bike saddle ($r = -.39$; $P = .08$). The other measures of erectile quality (tumescence activity units [TAUs] and rigidity activity units [RAUs] of both the base and tip of the penis) were lower in the cyclists, but did not reach statistical significance. The number of hours cyclists rode during the day of RigiScan Plus assessment was negatively correlated with penis tip RAU ($r = -.41$; $P = .04$), and tip TAU ($r = -.45$; $P = .04$). These data suggest that prolonged bicycle riding may have negative effects on nocturnal erectile function and indicate a need for innovative bicycle saddle designs.

Key words: Bicycle saddle, sexual dysfunction, impotence

In 1998, the occupational health clinic in a North American city police department reported a few complaints of genital numbness by biking police officers. The clinic distributed a self-administered questionnaire and reported that 15 of 23 biking officers who answered the questionnaire indicated they had some symptoms of genital numbness, groin pain, or impotence. As a follow-up to this information, the local union for the marine patrol unit requested that a reproductive health study be conducted of their bicycling officers to determine whether these symptoms were associated with bicycling. The National Institute for Occupational Safety and Health (NIOSH) responded to this request and conducted a reproductive health assessment of the bicycling patrol officers. The study protocol was reviewed and approved by the Human Subjects Review Board at the Centers for Disease Control and Prevention (CDC), NIOSH, before the study was initiated.

The marine patrol unit constitutes approximately 25 security officers who patrol city-owned marinas on bicycles. The officers spend much of their time riding on wooden piers and ramps. Most of their riding time was slow riding while they were seated on the saddle. The officers often interacted with the public or conducted their work while seated stationary on the bike, while often placing a hand on a pole or a boat for balance. Less often, the cyclists were observed in high speed or "pursuit" pedaling to quickly transport from one area to another.

Other city biking units were also invited to participate in the study. These included the police bicycle patrol, which serves the more traditional role of bicycling policemen in the community. These officers volunteered for this duty (rather than being assigned, as marine patrol officers are). In addition, men in a bicycle patrol unit from a security contractor company that provides tourist information specialists to the city were invited to participate in the study.

Mountain bikes were supplied by the city for each bicycling officer and the tourist contractor supplied bicycles to their cyclists. The newer bikes had full (front and rear) suspension systems to absorb the vibrations of the rough terrain. All city officers had been supplied with a split bicycle saddle in response to earlier complaints of genital numbness and sexual function problems. A majority (22 of 32) of the cyclists used this saddle at the time of the study. The city officers indicated that they had training in police bicycling techniques. Each cyclist (marine, city police, and contractor) uses a particular bicycle assigned to him and has adjusted it to his comfort.

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All cyclists were assigned by their supervisor to attend 1 of 10 presentations by NIOSH staff who described the study. The presentations were held at a hotel meeting room and all cyclists were assigned a meeting time by their supervisor while they were on duty. After a 15-minute presentation, the NIOSH project officer met with each cyclist in private to answer questions and to request informed consent.

All cyclists were asked to participate in all aspects of the study. These included bike saddle pressure measurements, hormonal analysis, a self-administered work and health questionnaire, a self-administered sexual function questionnaire, and RigiScan Plus penis rigidity assessment. Participants then mailed their completed questionnaires to NIOSH for data entry and analysis. Female cyclists were asked to participate in the bike saddle pressure measurements.

Follicle stimulating hormone, luteinizing hormone, and testosterone were measured because endocrine insufficiency could affect reproductive and sexual function. The hormones were measured in a sample of venous blood collected from the participant's arm (Schrader et al, 1993).

Sexual function was assessed by the International Index of Erectile Function Questionnaire (Rosen et al, 1997) and the Rigiscan Plus Rigidity Assessment System (Timm Medical Technologies, Eden Prairie, Minn; Burris et al, 1989). Again, the questionnaire was self-administered and returned by mail to NIOSH for data entry and analysis. The Rigiscan Plus was used to assess erectile function during participants' normal sleep patterns (Guay et al, 1996). The system is a computerized monitor worn on the leg, with two loops connected to the penis, one on the base and the other on the tip, and is used to study the penis during sleep. Men have penile erections during their sleep, and these provide useful physiologic information on erectile capability (Moore et al, 1997). This study was designed to compare the cyclists with another group for number of erections and the percentage of sleep time with an erection (Levine et al, 1994). For reliable results, participants were asked not to ejaculate for 1 day before the test; not to drink coffee, tea, caffeinated soft drinks, or alcoholic beverages for 2 hours before bedtime; and not to take sedatives, tranquilizers, muscle relaxants, or sleeping pills the night of the test because all these have been linked with impaired sexual function. Participants completed a brief, self-administered questionnaire upon awakening after Rigiscan Plus use. These questions were used to verify compliance with preconditions and to gather information on the biking time during the previous day and the quality of their sleep. The variable, number of sleep-time erections, measured by the Rigiscan Plus, is an assessment of the physiological ability to have a nocturnal erection. Other variables, including percentage of sleep time an erection occurred and rigidity activity units and tumescence activity units at the base and tip of the penis, are indicators of erection quality (ie, duration of erection, rigidity, and tumescence).

Five nonbiking men were recruited by word of mouth from among city employees and hotel staff to serve as a comparison group. These men agreed to participate in the Rigiscan Plus and hormone assessments.

It is believed that the pressure between the cyclist and the bicycle saddle may obstruct the nerves and blood vessels in the perineum (Kerstein et al, 1982; Broderick, 1999; Sommer et al, 2001, Sommer et al, 2001). The pressure exerted between the participant and the bicycle saddle was measured with a thin profile resistance-based pressure measurement mat (FSA, Vista Medical Ltd, Winnipeg, Manitoba) with a 40.64 cm x 40.64 cm measurement area and a 32 x 32 sensor resolution. The mat was placed over the bicycle saddle in a consistent orientation referenced to the nose of the saddle. The individual sensors on the pressure mat had a spatial resolution of 1.613 cm^2 (1.27 cm x 1.27 cm). The sensors were individually calibrated to a maximum pressure of 137.8 kPa (20 psi) by the manufacturer immediately before and immediately after the study. Any drift present in the sensors over the 2-week study period was corrected by interpolation between pre- and postcalibrations of the manufacturer.

An example of the pressure distributions measured with the system is shown in Figure 1. The pressure is distributed across the buttocks and thighs of the man sitting in a chair; pressure is concentrated on the urogenital triangle of a man sitting on (straddling) the bicycle saddle in a normal, upright position. The pressure is increased in the perineum as the cyclist leans forward in a pursuit position.

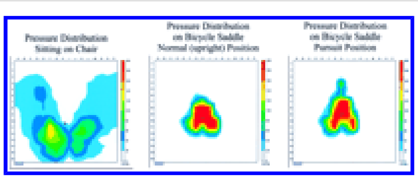

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Figure 1. Pressure distribution of a man sitting in a chair and in different positions on a bicycle saddle. The pressure is measured in mm Hg.

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At the beginning of each test session, the cyclist's bicycle saddle was measured for the length and width of the cushioned seating surface. The cyclists who participated in this study primarily used two types of saddles. As a result, characterizing the dimensions of the saddles was feasible. Of the 32 participants, 22 used saddle A variant, and 10 used saddle B variant. Figure 2 shows the saddles. Three dimensions of the saddles were of interest: saddle length, maximum saddle width, and length of the saddle nose. The saddle nose length was defined as the narrow front portion of the saddle and was defined by the sensor resting on the point where the narrow nose curves outward to form the portion of the saddle on which the ischial tuberosities (IT) rest. The boundary of the saddle nose is difficult to identify as an exact point on the saddle; however, it can be identified reasonably well within the spatial resolution of the pressure measurement system (described above).

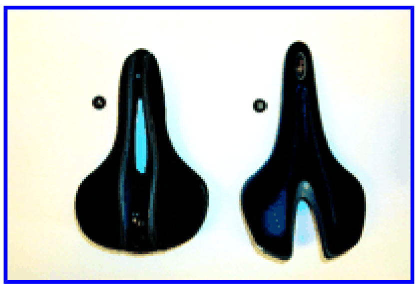

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Figure 2. The 2 major types of saddles used by cyclists. **(A)** Split saddle design. **(B)** V-groove saddle design.

Each subject's bicycle was mounted in a magnetic-resistance cycling trainer (Magturbo Ergo-10, Minoura, Hayward, Calif) allowing the subject to pedal his or her own bicycle while remaining stationary. The thin profile pressure measurement mat was placed over the bicycle saddle before subjects mounted their bicycles. By orienting the mat consistently with respect to the saddle nose, the location of any sensor's pressure registration could be determined. However, the location of pressure with respect to the saddle coordinate system does not provide direct information on the spatial pressure distribution with respect to the perineum of the rider. Localized pressure on the rider's perineal region can only be inferred on the basis of the distribution of pressure on the saddle.

Each cyclist pedaled his or her bicycle in a realistic simulation of 2 types of cycling: normal patrol riding, and pursuit riding, which simulates a chase or pursuit at higher speed. These 2 types of cycling are common in police work on bicycles. In normal riding, cyclists pedal their bikes at a leisurely pace; their posture is more relaxed, and they sit upright in the saddle. In pursuit riding, cyclists tend to adopt an aggressive style with a higher pedaling cadence and with their torso leaning more forward. A forward shift in the saddle pressure distribution was hypothesized in pursuit riding.

During these simulations of police-style cycling, saddle pressure was sampled at 5 Hz with each sample representing a scan over the matrix of 1024 (32 x 32) sensors. Each sample scan was written as a 32 x 32 matrix of pressure values. The single sample scan matrices were successively appended in a data file that was exported to ASCII format. The resulting ASCII data file consisted of a pressure matrix time series with 32 columns and a number of rows equal to 160 times the sampling duration (total rows = 32 rows x 5 sec^{-1} x sampling duration in seconds).

In postprocessing, each single sample scan pressure matrix was masked by eliminating rows and columns for individual pressure sensors outside of the nominal saddle dimensions. In this manner, only sensors that were in contact with the cushioned surface of the saddle were considered in the analyses. This served to eliminate spurious pressure registration on sensors under the saddle where the mat was folded inward. These masked matrices were of the dimensions n_i, n_j (where i represents the width sensors and j represents the length sensors) and were successively appended to form a masked pressure matrix time series. Pressure data from the masked pressure matrix time series were used to calculate several seating pressure summary measures with custom software written in Labview (National Instruments, Austin, Tex). The measures of interest were the average pressure on the saddle nose and the average pressure on the IT portion of the saddle.

For an individual sensor, pressure can be converted to an applied load (force) vector by multiplying the pressure value by the area of the sensor (F = P x A). When multiple sensors registered pressure the total pressure had to be calculated by dividing the total applied load by the total area over which the load was applied. This is because individual forces are vector quantities and can be summed, whereas pressure, which is a nonvector quantity, cannot be summed. The area over which the total load is applied was defined by the sensors registering non-zero pressure. Thus, the average pressure is expressed as shown in the following equation:

$$= \bar{\mathrm{P}} = \frac{\sum_i \sum_j [a \cdot \mathrm{p}_{ij}]}{\sum_i \sum_j [a \cdot n_{ij}(\mathrm{p}>0)]} = \frac{\sum_i \sum_j \mathrm{p}_{ij}}{\sum_i \sum_j n_{ij}(\mathrm{p}>0)} = \frac{\sum_i \sum_j \mathrm{p}_{ij}}{\mathrm{N}} \quad (1)$$

where a represents the area of an individual sensor (1.613×10^{-4} m^2), p_{ij} is the pressure on the ijth sensor in the pressure matrix, and $\Sigma\Sigma n_{ij}(p > 0)$, or N, is the number of sensors registering pressure. The numerator term, $\Sigma\Sigma a \cdot p_{ij}$, is the resultant average saddle load being applied by the rider to the bicycle saddle. This resultant saddle load is the sum of the pressure registered on each sensor multiplied by the sensor area, a, which can be factored from the summation. The denominator term, $\Sigma\Sigma a \cdot n_{ij}(p > 0)$, is the area over which this resultant force is applied, the number of sensors registering nonzero pressure times the sensor area, a. The total pressure is equal to the average of the individual sensor pressures because the area of the sensors are all identical. The resultant force applied to the bicycle saddle includes inertial forces and some fraction of the cyclist's body weight, which is dependent on the distribution of body weight between the saddle, pedals, and handlebars.

Cyclists and noncyclists participating in the erectile function tests were paid for their time and inconvenience.

Statistical analyses were conducted using the Statistical Analysis System for Windows (version 8.01; SAS, Cary, NC). Analysis of variance between the comparison group and the cyclists was calculated using the general linear models procedure. Correlations between variables was calculated using Pearson correlation procedures.

Results

Forty-two cyclists from the city attended the presentation of the study across 10 different sessions. Thirty-two cyclists (29 men and 3 women) had pressure measurements taken while riding their bikes. Rigiscan Plus measurements were conducted on 24 men. Equipment malfunctions or other incomplete data caused 2 men to be removed from the analyses. Rigiscan Plus data from 17 cyclists (13 from the marine patrol, 1 from the police bicycle patrol, 3 from the contracted tourist specialists) and 5 noncyclists were used for statistical analyses. The average age of the men in the Rigiscan Plus data was 29.5 years in the control group and 34.1 years among cyclists.

Twenty-four marine patrol officers (2 of whom were women) attended the information meeting. Of the 22 men in the marine patrol population, 7 did not participate in the Rigiscan Plus studies, which resulted in a 68% participation rate. Rigiscan Plus study participation rates from the contracted tourist specialists and the police bicycle patrol, most of whom rode on a voluntary basis, were 43% and 7%, respectively.

The cyclists rode an average of 5.4 hours a day and 91% indicated they had on occasion experienced numbness in their buttocks, scrotum, testicles, or penis during or after riding their bicycles. The numbness usually occurred after an average of 2 hours and 41 minutes of riding (range, 10 minutes to 8 hours) and lasted an average of 2 hours and 26 minutes (range, 2 minutes to 24 hours). All blood hormone values were within normal ranges.

The work/health questionnaire did not reveal any potential confounding factors that may have had a negative effect on erectile function, with the exception of 2 men who took medications for hypertension. None of their variables were outliers, and all analyses were conducted to both include and exclude these 2 men. The only effect of their inclusion in the data analyses was to increase the sample size; therefore, a decision was made to include the data from these 2 men in all data presented here.

The International Index of Erectile Function Questionnaire did not identify any men (cyclists or comparison group) with overt sexual dysfunction, and the results from both groups were not significantly different from published controls (Table 1).

View this table: [in this window] [in a new window]	Table 1. *International index of erectile function questionnaire*

The Rigiscan Plus data in Table 2 provide information on sleep erection events. Figure 3 presents examples of Rigiscan Plus graphs. The number of sleep erection events (noncyclists, 3.8 ± 1.3; cyclists, 4.3 ± 1.7; P = .56) was not statistically different between the groups, indicating that the basic neurophysiology of erectile function was intact in cyclists. However, measures of erection quality were lower in the cyclists. The percentage of the sleeping time a man had an erection was statistically reduced (P = .008) in biking police (27.1% ± 9.75%) compared with men who did not ride bicycles (42.8% ± 13.2%). This duration percentage is negatively correlated with average hours a day the man rode his bike (r = -.41; P = .05), the number of days a week he rode (r = -.55; P

= .009), and the average pressure exerted on the nose of the bike saddle (*r* = -.39; *P* = .08). The other measures of erectile quality (RAU and TAU of both the base and tip of the penis) were lower in the cyclists, but they did not reach statistical significance. The number of hours the man rode his bicycle on the day of the RigiScan Plus assessment was negatively correlated with penis tip RAU (*r* = -.40; *P* = .07), and tip TAU (*r* = -.45; *P* = .04).

View this table: [in this window] [in a new window] Table 2. *RigiScan Plus results*

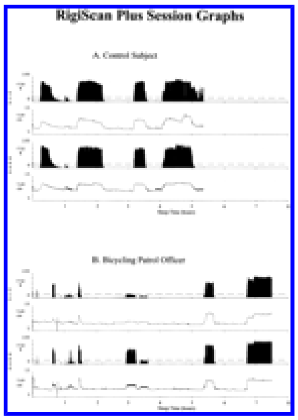

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Figure 3. Rigiscan Plus graphs. **(A)** A control subject who slept about 5.5 hours with erectile events lasting 43% of the sleep period. **(B)** A bicycling officer who slept about 7.5 hours and had erectile events lasting 20% of the sleep period.

Approximately 60% of the men provided information on body weight (19 of 32 cyclists studied; 14 of 22 men with RigiScan Plus data). A positive correlation, although not statistically significant, was seen between average body weight and saddle nose pressure (*r* = .45; *P* = .06). A negative correlation, although not statistically significant, was observed between body weight and erectile function as measured by the International Index of Erectile Function Questionnaire (*r* = -.44; *P* = .08). No other correlations with body weight were noted.

The bicyclists sat on the saddle in such a way that approximately 22% of the load (weight) supported by the saddle was distributed on the nose of the saddle and 78% of the weight on the saddle was distributed on the "sit bone" portion of the saddle. These percentages corresponded to average pressures of 2.3 ± 1.7 and 2.9 ± 1.0 pounds per square inch (psi) on the nose and "sit bone" portion of the saddle, respectively. (These pressures are 15.9 ± 11.7 and 20.0 ± 6.9 kPa). Even though the nose supported a lower percentage of the total load on the saddle (less than a quarter of the weight on the saddle is distributed on the nose), its smaller surface area acts to increase the localized pressure on the rider in this region. It is hypothesized that pressure exerted on the nose of the saddle is most detrimental to the nerves and blood vessels in the perineum (Solomon and Cappa, 1987; Anderson and Bovin, 1997; LaSalle et al, 1999; Schwarzer et al, 1999).

No differences were observed between the normal patrol and pursuit cycling styles. The hypothesis of a forward shift in the pressure distribution (ie, higher saddle nose pressure) associated with pursuit-style cycling was not supported.

Discussion

The statistically significant difference observed between the comparison group and the cyclists for the percentage of sleep time a man had an erection would indicate that cyclists have reduced erectile function. This interpretation is limited, however, by the self-selected nature of the comparison group. Because this measurement is also significantly correlated with average number of hours the cyclist rides and the amount of pressure on the bicycle saddle, this increases the likelihood that this subclinical erectile impairment is related to the man's biking occupation. This is further supported by a recent report from the Massachusetts Male Aging Study, which indicates an greater risk of erectile dysfunction associated with riding a bicycle more than 3 hours a week (Marceau et al, 2001). The observed differences are probably not due to normal variation because the number of sleep erections was not affected, indicating that the basic erectile function control by the brain was intact in cyclists.

Three of the cyclists in the study slept during the day because they worked the night shift. Some studies have reported that sleeping during the day may disrupt rapid eye movement (REM) sleep, but there may also be an adaptation to normal sleep patterns with consecutive days of daytime sleep (Salsh et al, 1988). Most nocturnal erections take place during REM sleep (Moore et al, 1997). These cyclists worked the night shift as their standard tour of duty and were probably able to adapt to day sleeping. All had erections during their sleep (average 5.3 erections), indicating normal REM sleep.

Some sleep clinic studies of nocturnal erections report a "first-night effect," indicating fewer erectile events the first night of assessment, possibly due to the strange environment or equipment being worn (Jovanovic, 1972). Studies with the Rigiscan indicate that there is not a first-night effect, although more nights of data are useful for diagnosis of sexual dysfunction (Burris et al, 1989; Levine and Carroll, 1994). Without a first-night effect, a single night assessment provides sufficient data for a cross-sectional population study as presented here.

Our research team noticed that many cyclists conducted much of their work unnecessarily on the saddle. Many of them talked with the public, rested, and made general observations while still sitting on the bicycle saddle. Many men remained on the saddle with their feet on the ground or on the pedals and used a hand to support themselves against a pole, a boat, or anything that would support them. This increases the amount of time that pressure is unnecessarily applied to the nerves and blood vessels of the perineum (Sommer et al, 2001,Sommer et al, 2001).

The average saddle nose pressure measured in this study was approximately 2.3 psi. The findings by Rogers (1973) as cited by Armstrong (1985) suggest that ischemic tissue injury would occur after approximately 280 minutes (<5 hours) of exposure to localized pressure of 2.3 psi. Some cyclists in this study exhibited average saddle nose pressures that exceeded 4.6 psi (32 kPa) during the saddle pressure testing. This level of pressure corresponds to a tolerance time of less than 156 minutes (~2.5 hours).

Higher pressures on the nose of the bicycle saddle were believed to be more detrimental to erectile tissues than pressures toward the IT portion of the saddle where the ITs bear the majority of the contact pressure. Pressures registering on the nose of the saddle are likely to be compressing tissues in the perineum rather than the tissues under the tuberosities. Thus, the analysis of the pressure distribution on the saddle nose was emphasized. Because the dimensions of the saddle are known, and because the pressure mat was oriented consistently toward the saddle nose, the fore-aft location of saddle nose pressures could be determined. It is important to emphasize that the spatial distribution of pressure is known relative to only the local saddle coordinate system (as defined by the saddle nose). No method for determining the orientation of the rider's perineum with respect to the saddle coordinate system could be developed, so the spatial relationship between pressure measured on the saddle and pressure imparted on the rider's perineum can only be inferred.

The saddle pressures were measured in a simulated riding scenario and it is possible that riding on wooden piers and ramps might result in more jolting-type pressure increases relative to the smooth spinning on the cycling trainer.

That bicycle saddle manufacturers have acknowledged the problem of groin numbness in cyclists is evident in the abundance of alternative bicycle saddle designs in which the designers have removed material from the midline of the saddle. These designs include grooves, wedges, or completely split halves, which are all intended to remove pressure from the tissues of the perineum. Although these alternative saddle designs may prevent pressure from being taken up in the midline of the perineum, the reduction in total saddle area must result in an increase in pressure in the regions lateral to the groove. Because these grooves typically occupy a much larger proportion of the available surface area on the saddle nose than on the IT portion of the saddle, they have the potential to create a larger relative increase in pressure on the saddle nose. With 22% of the total pressure located on the saddle nose, this is a substantial increase.

Some spurious low levels of pressure were observed in the midline grooves of the saddles, where no saddle material was present. This was attributable to one of two phenomena, either an increase in the effective surface area of the saddle cushion material due to its compression under the load of the seated cyclist, or measurement artifacts on the pressure-sensitive mat from the hammocking effect (Ferguson-Pell and Cardi, 1993). Theoretically, there can be no pressure where no saddle material exists. However, hammocking of the pressure-sensitive mat may have occurred across the midline groove of the saddles and resulted in low levels of contact pressure registering in this grooved area with no saddle cushion material underneath. This hammocking effect has been shown to result in errors of up to 5-10 mm Hg with the pressure mat used in our study (Ferguson-Pell and Cardi, 1993), corresponding to 0.67-1.33 kPa (4%-8% of the 16 kPa). Although the spurious pressure due to hammocking acts to increase the total pressure recorded on the saddle, it does not affect the areas of high pressure, which are observed to be lateral to the midline groove. With grooved designs, the pressure in these areas is higher than it would be if no midline groove existed.

A larger study to evaluate more biking officers with various bicycle saddle designs is needed to substantiate these findings and to determine safe and healthy work practices and saddle designs.

Conclusions

Although none of the cyclists studied were impotent according to the International Index of Erectile Function Questionnaire, the decrement in erectile quality and the high percentage of men complaining of genital numbness could be an indication of a developing reproductive health problem. The nose of the bicycle saddle exerts excessive pressure to the perineum, which appears to decrease penile erectile quality.

Recommendations

Men who ride bicycles many hours a day should be concerned about the pressure exerted on the perineum. They should take rest breaks off the bicycle saddle when possible. They should also consider replacing their bicycle saddle with a design that does not have a protruding nose or replacing their bicycle with one that has a recumbent design. Whereas alternative saddle designs may decrease pressure applied to the perineum, the overall health effects of long-term use of these saddles is unknown and it needs to be evaluated.

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Sleep time is the normal amount of time a man sleeps. Because some men worked nights, their normal sleep time was during the day. These men wore the Rigiscan Plus during their daytime sleep session rather than at night. Sleep time was measured with the Rigiscan Plus. When the Rigiscan Plus is turned on, the first 15 minutes are a characterization session. The time interval from the end of the characterization time until the Rigiscan Plus is turned off is measured as sleep time.

Rigidity activity units (RAUs) are a time-intensity measurement that represents the area under the rigidity during an erectile event. RAU is calculated by summing the rigidity values for the duration of a qualified event and dividing by 2 and multiplying by 100. The value 2 is used because there are 2 rigidity samples taken per minute, and the value of 100 is used to remove the percent.

Tumescence activity units (TAUs) are a time-intensity measurement that represents the area under the tumescence curve above the baseline during an erectile event. It is proportional to the percentage increase in tumescence over baseline. TAU is calculated by summing the tumescence over baseline minus the baseline tumescence and dividing by 4 times the baseline. The value 4 is used in the calculation because there are 4 tumescence samples taken per minute.

Acknowledgments

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