Effect of Bicycle Saddle Designs on the Pressure to the Perineum of the Bicyclist

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ABSTRACT

LOWE, B. D., S. M. SCHRADER, and M. J. BREITENSTEIN. Effect of Bicycle Saddle Designs on the Pressure to the Perineum of the Bicyclist. *Med. Sci. Sports Exerc.*, Vol. 36, No. 6, pp. 1055–1062, 2004. **Purpose:** Increasing awareness of an association between bicycling and male sexual dysfunction has led to the appearance of a variety of bicycle saddles that share the design objective of reducing pressure in the groin of the cyclist by removal of the narrow protruding nose of the saddle. This study compared three of these saddle designs to a traditional sport/road racing saddle with a narrow protruding nose in terms of pressure in the region of the perineum (groin) of the cyclist. **Methods:** Saddle, pedal, and handlebar contact pressure were measured from 33 bicycle police patrol officers pedaling a stationary bicycle at a controlled cadence and workload. Pressure was characterized over the saddle as a whole and over a region of the saddle assumed to represent pressure on the cyclist's perineum located anteriorly to the ischial tuberosities. **Results:** The traditional sport/racing saddle was associated with more than two times the pressure in the perineal region than the saddles without a protruding nose ($P < 0.01$). There were no significant differences in perineal pressure among the nontraditional saddles. Measures of load on the pedals and handlebars indicated no differences between the traditional saddle and those without protruding noses. This finding is contradictory to those studies suggesting a shift toward greater weight distribution on the handlebars and pedals when using a saddle without a nose. **Conclusions:** The recommendation of a saddle without a narrow protruding nose appears to be justified to reduce pressure to the perineum of the bicyclist. **Key Words:** BICYCLING, ERECTILE DYSFUNCTION, IMPOTENCE, GROIN PRESSURE

Several studies have reported an association between bicycling and erectile dysfunction and/or impotence (4,8,10,12,15,17,19,20). In an injury clinic report in 1991, Mellion (13) asserted that male impotence had been documented as an occasional problem in cyclists, and that the incidence of the problem was not known, "...but thought to be extremely low." (p. 64). More recent data suggests otherwise. Andersen and Bovin (1) reported that 21% of sport cyclists reported genital numbness after a bicycle race and 13% reported impotence. Sommer et al. (21) reported a 61% incidence of genital numbness among cyclists and a 19% incidence in erectile dysfunction among cyclists riding more than 400 $km \cdot wk^{-1}$. In a study of police patrol cyclists, our group found inverse relationships between contact pressure on the saddle nose and weekly duration of cycling time with measures of nocturnal erectile quality (16). Police officers who exhibited more pressure on the saddle nose and who spent more time on their bicycle saddle had nocturnal erections for a lower percentage of their sleeping time. In addition to these data, it has been suggested that the prevalence of cycling-associated erectile problems is likely to be under-reported in the literature (22). Our group began investigating this problem as an occupational health concern in 2000 when complaints of groin numbness were received from officers in a police bicycle patrol unit. Our focus has been mostly on police officers, security officers, and emergency medical personnel who use bicycles as part of their work, rather than on recreational/sport bicyclists. There are approximately 50,000 police officers who are members of bicycle patrol units in the United States. Police and security patrol officers often report spending over 5 $h \cdot d^{-1}$ sitting on a bicycle saddle. Many of these officers also bicycle recreationally while off duty. Male police and security patrol officers and emergency medical personnel who ride a bicycle as part of their occupation may be at greater risk for groin numbness, erectile dysfunction, and even impotence than typical recreational/sport cyclists because they are likely to experience a longer duration of exposure to groin pressure, they are likely to be heavier, and they typically carry equipment that adds to the load their body creates on the saddle.

Urologists have speculated that bicycle saddles without a protruding nose will reduce pressure on the pudendal nerves and vasculature, thereby decreasing the likelihood of cycling-related erectile dysfunction and impotence (7,18). As reasonable as this hypothesis appears, it is supported by relatively little experimental data. Schwarzer et al. (18) measured decreases in transcutaneous penile oxygen pressure for cyclists sitting on four designs of bicycle saddles including a saddle without a protruding nose. Although all of the saddles were associated with a decrease in penile

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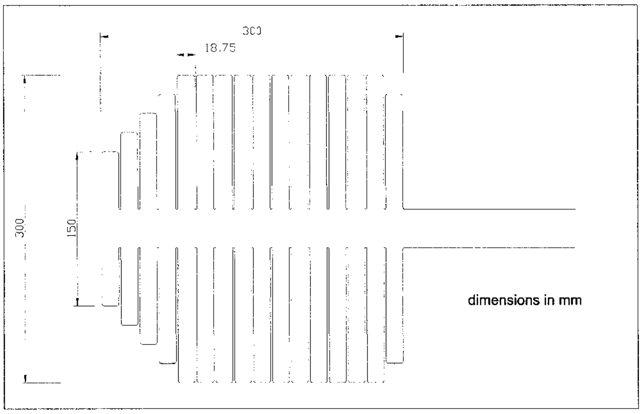

FIGURE 1—Pliance pressure sensor mat. The mat is comprised of a matrix of 234 sensors that are 1.875 × 1.875 cm. It is tapered in the corners for better fit over a bicycle saddle and there are cuts between the rows of sensors to form "fingers" that wrap around the contour of the saddle.

oxygen pressure, the saddle without a protruding nose exhibited a decrease that was 3–4 times less than those of the racing style saddles with protruding noses.

In spite of these recommendations, the so-called "ergonomic" saddle designs have not been universally embraced by cyclists. Our informal discussions with numerous police and security patrol cyclists has revealed substantial skepticism, and often outright rejection, of bicycle saddle designs that do not incorporate a traditional narrow protruding nose. Some scientific literature suggests that saddles designed with cut-out regions and without a narrow nose may adversely affect the position and weight distribution of the cyclist on the bicycle. Bressel and Larson (3) reported increases in EMG of the triceps brachii, anterior pelvic tilt, and trunk inclination with use of both complete and partial anterior-medial cutout saddles, relative to a traditional racing/sport saddle. These findings suggest an increase in the percentage of body weight supported on the handlebars with the anterior-medial cutout saddles. Dickson (5) indicated a tendency for a cyclist to slip off the front of one particular saddle without a protruding nose. Anecdotal reports we have received from cyclists suggest that many believe that the absence of the saddle nose compromises stability, maneuverability, and handling of the bicycle.

The present study was conducted to examine the effect of bicycle saddle design on groin pressure. The primary objective was to compare a representative sample of nonprotruding nose saddle designs with a traditional narrow-nosed racing/sport saddle with respect to the magnitude and distribution of pressure on the perineal region of the cyclist. A secondary objective of the study was to examine differences in load distribution on the feet and hands of the cyclist that might be attributed to the absence of the protruding saddle nose.

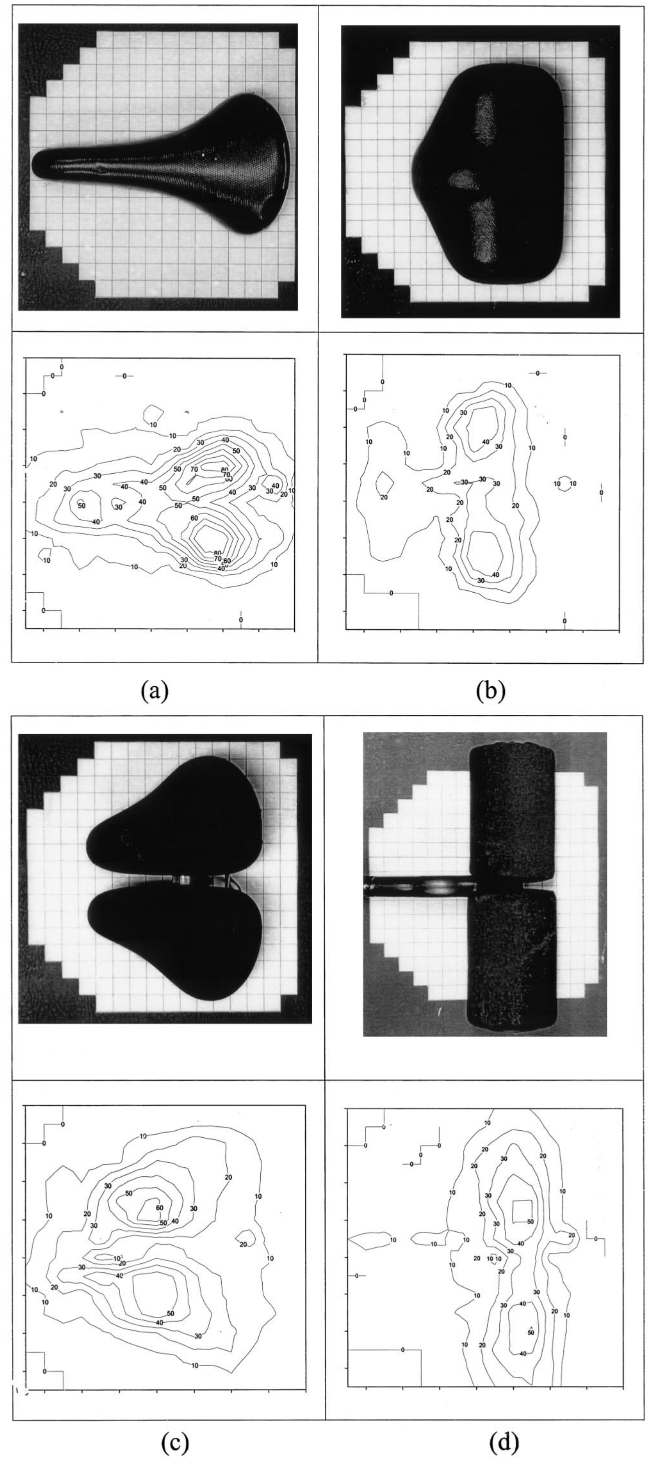

FIGURE 2—Bicycle saddles evaluated in the study shown against a paper replica of the Pliance mat sensor matrix. (a) saddle A, traditional road racing/sport saddle (with a typical narrow protruding nose); (b) saddle B, full saddle with no protruding nose; (c) saddle C, split saddle with no protruding nose; (d) saddle D, padded cylindrical sitting surface T-mounted to a seat post (seat post projects to the left of the photo). A representative average pressure distribution is shown below the photograph of each saddle.

METHODS

Approach to the problem and experimental design. Four bicycle saddles were chosen to represent four types of saddle designs. An evaluation of every "ergonomic" bicycle saddle design available on the consumer market would be a daunting if not impossible task. The goal in this investigation was to select a manageable number of saddles that were representative of "ergonomic" saddles designed without the narrow protruding nose of the traditional racing/sport saddle. The traditional racing/sport bicycle saddle with a narrow protruding nose was represented by the saddle shown in Figure 2a, and is designated as saddle "A." Three other saddle designs were represented by the saddles shown in Figures 2b, 2c, and 2d, and are designated as saddles "B," "C," and "D," respectively. These saddles share the common design concept of removing the narrow protruding nose to reduce pressure on the anterior perineum. The physical characteristics of the saddle designs were quite different, but these three were certainly not exhaustive of all of the saddles available in the consumer market. Saddle B was a continuous padded surface without a protruding nose. Saddle C had two completely split halves with minimal protrusion in the way of a nose relative to more traditional saddles. Saddle D was essentially two padded cylinders mounted on both sides of a seat post. Saddle design C provided adjustability for the gap between the two split halves. This gap distance was set to approximately one half of the range of adjustment for all participants using this saddle. It was not adjusted for individual cyclists.

Officers were assigned to one of the four saddle conditions in a nested, quasi-randomized design. Saddles A, B, C, and D were randomly assigned among every group of four successive officers who volunteered to participate. We were not able to predict beforehand how many officers would volunteer for participation, so a full *a priori* randomization risked finishing with an unbalanced nesting of participants in each saddle condition. By randomly assigning four saddles for each successive group of four participants, we ensured that the nesting would be close to balanced, regardless of the number of officers volunteering to participate.

Participants. Bicycle patrol police officers, security officers, and emergency medical personnel were recruited to participate in this study, which took place at the International Police Mountain Bike Association (IPMBA) annual meeting in May 2003. Thirty-three ($N = 33$) officers volunteered to participate in the study during the meeting week, representing police bicycle units from across the United States and internationally. No *a priori* sample size calculations were conducted. Study enrollment was limited only by the voluntary participation rate of the officers at the IPMBA meeting. All officers attending the meeting were eligible to participate. A technical problem with the instrumentation yielded invalid data for one of the 33 participants. Analyses reported included data from 32 participants, of which 31 were male officers. (Approximately 10% of all bicycle patrol police officers are female.) The nested design had eight participants assigned to each of the four saddle conditions as described above. Body weight was obtained for each officer while wearing all of the police-issue equipment he/she would normally carry on patrol. Body weights of officers plus their police issue equipment ranged from 56.6 to 153.8 kg (93.7 ± 18.1).

Officers self-reported the number of hours per week they typically spend riding a bicycle, including both duty and off-duty/recreational cycling. This averaged 19.4 ± 14.0 $h \cdot wk^{-1}$ for all participants. Some officers reported weekly bicycling time as high as 50 h including duty and off-duty/recreational cycling.

Instrumentation and apparatus. Synchronous measurements of hand, foot, and saddle pressure were made with the Novel Pedar and Pliance pressure sensor systems (Novel Electronics Inc., St. Paul, MN) at a sampling rate of 20 Hz. The Pliance bicycle saddle pressure mat was custom fabricated by Novel Electronics for our bicycle saddle pressure measurement applications. It consists of a 16 × 16 matrix of square sensors (1.875 × 1.875 cm) that is tapered in the corners, yielding 234 sensors (see Fig. 1). Partial length cuts between rows of the sensor matrix allowed the mat to conform to the irregular shape of the saddles. The Pedar insoles were Novel's standard insole configuration; each insole consisting of 99 individual sensors of nonuniform sensing areas. The left foot insole was placed inside the left shoe of the participant, while the right foot insole was wrapped around the handlebars of a stationary ergometer to measure pressure between the hand and the handlebars. There was no overlap of the Pedar insole sensor with itself when wrapped around the handlebar. Measures reported for foot and hand pressure are for the left hand and foot. It was assumed that the average pressure would be symmetric between the left and right hand and the left and right foot so that the right hand and foot would be subjected to a similar pattern of pressure.

The Pliance bicycle saddle mat was calibrated to 300 kPa ($30\ N \cdot cm^{-2}$). The Pedar insole sensors were calibrated to 600 kPa ($60\ N \cdot cm^{-2}$). The pressure time series for each individual sensor was low-pass filtered (5-Hz cut-off) with a sixth-order Butterworth digital filter before the pressure and load summary measures were calculated with custom software written in Labview (National Instruments, Austin, TX).

Measurements of saddle, pedal, and handlebar pressure were made during cycling on a modified Tunturi Professional stationary bicycle ergometer (Tunturi Oy Ltd., Turku, Finland). The Tunturi ergometer was modified with a sleeve welded to the seat support structure so that the sleeve accepted a standard bicycle seat post that could be adjusted in height by a set-screw. Any bicycle saddle could be attached to the ergometer and adjusted in height. The crankarm length of the ergometer was 17.0 cm and the pedals were mountain bike block style *without* toe clips, clipless cleat entry, or any other interlock between the shoe and pedal enabling an upward pulling force in the pedaling motion. The handlebar position of the ergometer was adjustable in a circular path as viewed sagittally. Pedaling resistance of the ergometer was set to a constant load yielding a power output of 150 W at a pedaling cadence of 70 rpm, the cadence at which participants were instructed to pedal. Participants were given real-time feedback of their pedaling cadence from a digital cycle computer display.

Procedure. All procedures were reviewed and approved by the Human Subjects Review Board of our institution. Written informed consent was obtained from all officers before their participation in the study. Officers were not compensated for their participation. Officers were asked to select and adjust the height of the saddle and the position of the handlebars before the measurement trial. They were given time to familiarize themselves with the ergometer before selecting their preferred saddle height. The saddle height and handlebar position adjustments were made based only on the subjective preference of the participant. Officers were instructed to pedal the stationary bicycle ergometer at a cadence of 70 rpm at a preselected resistance equivalent to a power output of 150 W. Once the participant's pedaling cadence was steady and close to 70 rpm, the pressure recording was triggered. Pressure on the saddle, left foot, and left hand were measured for 40–60 s during this controlled pedaling trial, after which the participant could stop pedaling. Fatigue was not a factor in the short-duration trial. Participants refrained from wearing cycling gloves but were asked to wear all of the police-issue equipment they would normally carry on duty, which typically includes a heavy utility belt with firearms, radio, handcuffs, nightstick, and possibly even a bullet-proof vest.

Footwear varied widely among the participants. Several officers wore an athletic "cross-training" style shoe, others wore a stiffer sole police-issue cycling shoe, and others wore footwear that fit neither of these categories. Officers wore their police-issue pants, which were quite different from the Lycra sport cycling shorts that incorporate a padded chamois. Police-issue cycling shorts may provide less cushioning between the groin and the saddle.

Measures of saddle pressure characterization. We have found that localizing the spatial distribution of sitting pressure with respect to the bicycle saddle can be accomplished reasonably well by orienting the Pliance sensor mat in a consistent and repeatable manner with respect to landmarks on the saddle. More sophisticated methods of spatially referencing the pressure sensing media to the saddle have been described (9); however, the more important spatial referencing is that between the pressure sensing media and the anatomy of the cyclist. Localizing the spatial distribution of pressure with respect to anatomical regions of the cyclist is far more desirable, yet it is also less certain because of individual variability in anthropometry and positioning on the bicycle.

The method we adopted for spatially referencing the Pliance sensor mat with respect to the anatomy of the cyclist relies on the identification of landmarks from the ischial tuberosities. The pressure measures of interest were pressure over the full saddle and the pressure in the region of the saddle corresponding to the perineum of the cyclist. The region of perineal pressure was identified spatially in the following manner: two distinctive local maxima in the saddle pressure distribution were clearly identifiable for all participants. These local maxima were assumed to correspond to the region of the Pliance mat lying directly under the ischial tuberosities. The pressure maxima of the ischial tuberosities were used as reference landmarks by first creating a line segment that connected these two pressure maxima. A second line segment was identified that perpendicularly bisected the segment joining these two local maxima. It was assumed that the perineal region was located symmetrically about this second segment in the portion of

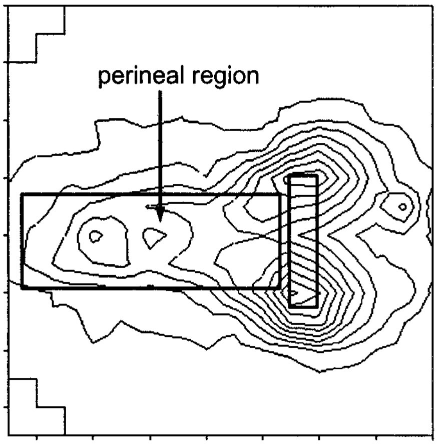

FIGURE 3—Procedure for spatial location of pressure on the perineum. A rectangle enclosing the local maxima at the ischial tuberosities was identified (1 sensor in width). The perineal region was defined by a second rectangular region, three sensors wide, that perpendicularly bisected the segment connecting the ischia and was completely anterior to the segment connecting the ischia.

the segment anterior to the first segment that connected the local maxima of the ischial tuberosities. The length of the region was the anterior distance between the segment connecting ischial tuberosities and the front edge of the Pliance sensor mat. (This procedure is shown graphically in Fig. 3). The lateral-medial width of the region was limited to the spatial resolution of the individual sensors of the Pliance mat. A width of three sensors (5.625 cm) was used in calculations of the perineal regional pressure. Measures of pressure in this perineal region were the peak pressure (i.e., the individual sensor exhibiting the highest average pressure) and the average pressure over all sensors registering pressure in the region. For measures of saddle pressure the average pressure over a region, $\bar{P}$, was calculated based on Equation 1:

$$\bar{p} = \frac{1}{na}\sum_i \sum_j a \cdot p_{ij} = \frac{1}{n}\sum_i \sum_j p_{ij}, \qquad [1]$$

where p_{ij} is the pressure on the sensor in row i, column j of the region, n is the number of sensors in the region registering nonzero pressure, and a is the area of an individual sensor (3.516 cm^2). The Pliance mat is a matrix of square sensors of uniform dimensions, thus, the average pressure over a given region is equal to the average of the individual sensor pressures measured in that region.

Measures of foot and hand load. Pressure on each Pedar insole measuring left foot and left hand pressure were converted to an applied load on each insole by multiplying each sensor pressure by the sensor area and summing over all sensors of the insole. Vector directions of the load calculated for the foot and hand could not be determined because the orientation of the plane of the pedal changes throughout the pedal revolution and the handlebar contact pressure was measured with the insole sensor wrapped around the cylindrical handlebar surface.

Spectral frequency analysis of the load on the left foot load time series revealed a clear spectral peak at a frequency

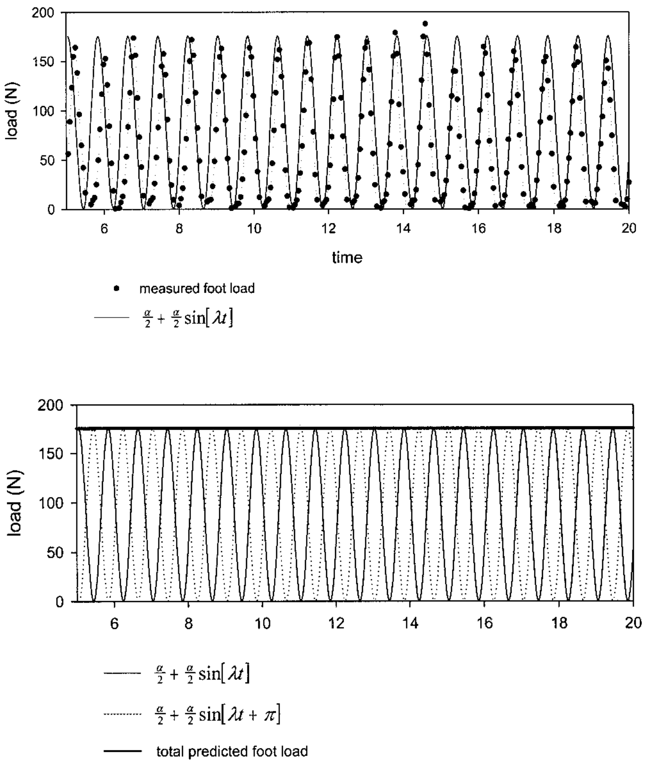

FIGURE 4—Calculation of average foot load. The foot load time series oscillated sinusoidally at a frequency close to the pedaling cadence of 70 rpm. This frequency was calculated by spectral frequency analysis. A sinusoid function of this frequency and amplitude was fit to the foot load time series. Right foot load was assumed to be equivalent with the left foot load shifted in phase by one half of the pedal revolution. The left plus right foot load time series was the sum of these two functions.

that averaged 1.19 Hz, corresponding to a cadence of 71 rpm. Thus, participants did maintain a pedaling cadence close to the 70 rpm that was specified. Variation about this mean was small (SD of 2 rpm), and because the resistance of the ergometer was constant, absolute workload was considered to be constant for all participants. The periodicity of each foot load time series was well suited for a fit with a sinusoid function of the form:

$$\text{predicted foot load} = \frac{\alpha}{2} + \frac{\alpha}{2}\sin[\lambda t], \qquad [2]$$

where $\lambda = [s/2\pi f]$, s is the sampling rate in hertz, and f is the frequency associated with the spectral peak of the time series (equivalent to the cadence). The frequency λ and amplitude α scaling of each sine function were determined in the spectral frequency analyses. The fit of the sinusoid functions to the measured foot load data were excellent as seen in the Figure 4 example.

It was assumed that the right and left foot load would be symmetric with a phase shift of one half of the pedal revolution. The foot load of the left and right foot combined was assumed to be equal to the sum of this sine function and the same sine function phase shifted by one half of a pedal revolution (see Fig. 4). Based on the assumption of left/right hand symmetry, average total hand load was assumed to be equal to two times the average left hand load measured on the Pedar insole.

Statistical procedures. The statistical models included independent variables for saddle, a covariate for body weight, and a body weight × saddle interaction. (The interaction between body weight and saddle was never statistically significant and was thus dropped from the final reduced models.) Probability of Type I error was set at 0.05 for all statistical tests unless denoted otherwise by a smaller P value. For dependent measures in which saddle reached statistical significance at the 0.05 level, Tukey's Studentized range tests were conducted for comparisons between individual treatment means.

RESULTS

Pressure on the saddle. Average pressure and peak localized pressure were calculated over two regions on all saddles. Measures of pressure over the full saddle were calculated from all sensors on the Pliance mat registering nonzero pressure. Measures of pressure on the perineal region were calculated in the same manner restricted to the region corresponding to the perineum as described previously. Peak and average pressure for both regions are shown by saddle in Figure 5.

The general linear modeling procedure was conducted for average and peak pressure over the full saddle and the perineal region of the saddle. The body weight × saddle interaction term was not significant in any model and was thus deleted in the reduced models reported. The covariate for body weight had a significant effect on the average full saddle pressure ($F_{1,27} = 30.14$, $P < 0.001$) and the peak and average pressure in the perineal region ($F_{1,27} = 7.95$, $P < 0.01$; $F_{1,27} = 9.53$, $P < 0.01$), but not on the peak full saddle pressure.

The traditional sport/racing saddle with the narrow protruding nose (saddle A) was associated with two times the average perineal pressure of the three nonprotruding nose saddles (37.2 kPa vs 19.0, 19.4, and 16.4 kPa; $F_{3,27} = 29.81$, $P < 0.001$). The nonprotruding nose saddles (B, C, and D) were not significantly different with respect to their associated average perineal pressure. Peak perineal pressure was also significantly higher for the traditional saddle (70.4 kPa for saddle A vs 41.7, 41.5, and 42.0 kPa for saddles B, C, and D; $F_{3,27} = 9.29$, $P < 0.001$), but this relative difference between the traditional and nonprotruding nose saddles was not as large as that for average perineal pressure. Average pressure over the full saddle was significantly higher for saddle A than for saddle D ($\alpha = 0.05$), whereas saddles B and C did not differ from A or D. Peak pressure over the full saddle was not different for saddles A and C or saddles B, C, and D. Groupings by statistical significance, from Tukey's Studentized range test ($\alpha = 0.05$), are shown in Figure 5.

Distribution of load on the pedals and handlebars. Average foot plus hand load as a function of saddle are shown in Figure 6. The body weight covariate had a significant effect on foot plus hand load ($F_{1,27} = 8.91$, $P < 0.01$). The variability in average foot load among participants was somewhat unexpected because pedaling resistance was constant for all participants. Body weight of the officers explained 47% of this variance ($P < 0.01$). Inter-

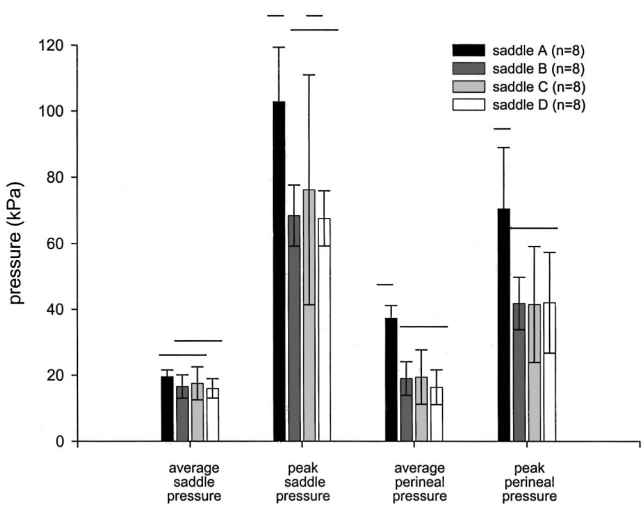

FIGURE 5—Full saddle pressure and perineal region pressure for saddles A, B, C, and D. *Horizontal bars* denote groupings by statistical significance ($P < 0.05$). For peak saddle pressure, saddle A was different from saddles B and D, but not C. Full saddle pressure did not differ among saddles B, C, and D.

estingly, body weight exhibited poor (and nonsignificant) correlation with average load measured at the hands ($r^2 = 0.06$, $P = 0.17$). The hypothesized increase in relative loading on the feet and hands with the no-nose saddles was not supported. There were no significant differences among the saddles in the load calculated for the hands plus feet ($F_{3,27} = 0.33$, $P = 0.81$). *Post hoc* sample size calculations for this effect size showed that $n = 88$ participants per saddle group ($N = 352$) would be needed to demonstrate statistical significance at the 0.05 significance level with a power of 0.80.

These measures of hand and foot load are not measures of load in the vertical axis that functions to support the mass of the cyclist. This is particularly the case for the load on the hands, which may include gripping force around the handlebars. As a result, the absolute levels of the hand and foot load reported are less meaningful than the relative comparisons of these measures between saddles.

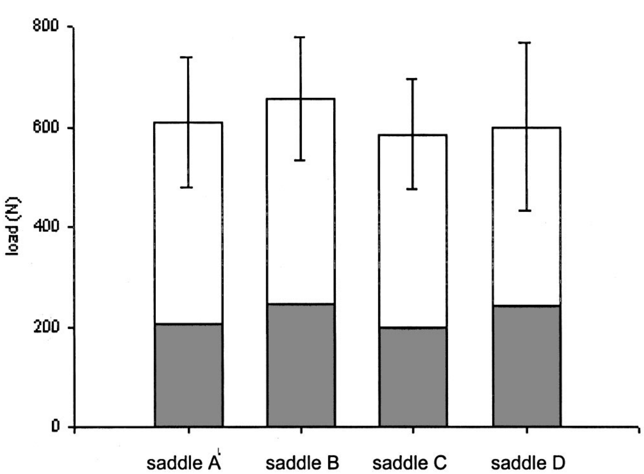

FIGURE 6—Foot and hand load associated with the use of the saddles. Foot load was calculated as shown in Figure 4. Hand load was calculated as double the average left hand load, assuming symmetry between the left and right hands. Foot load is represented by the *shaded region* of the bar, hand load by the *unshaded region*. SD bars are for the sum of the foot plus hand load.

DISCUSSION

Bicycle saddle pressure is a function of numerous variables that cannot be comprehensively investigated in any single study. These variables are related to the anthropometrics and body position of the cyclist, the physical characteristics of the saddle, or the type of cycling. Physical characteristics of the saddle that influence the distribution of pressure on the cyclist are the geometry/shape and the cushion compliance. The traditional saddle evaluated in the present study (saddle A) was associated with an average pressure of 19.5 kPa over the full saddle and an average pressure over the perineal region of 37.2 kPa. Qualitatively, the traditional saddle examined in the present study was fairly stiff with relatively little cushion compliance compared to many saddles used by bicycle patrol officers. However, this traditional-design saddle was associated with an average *full saddle* pressure that was significantly higher than only one of the three nonprotruding nose saddles (saddle D). Thus, we conclude that the significantly higher pressure in the *perineal* region associated with the traditional saddle is more likely influenced by the saddle geometry and shape than by its cushion properties.

The anthropometry of each cyclist's perineal region could not be individually characterized. This necessitated a method for inferring the spatial location of the perineum with respect to the saddle so that the spatial distribution of pressure registering on the pressure mat could be mapped to the perineum. The method adopted to identify this spatial location was based on landmarks assumed to correspond with the ischial tuberosities. The representations of average saddle pressure shown in Figure 2 are two-dimensional planar representations of pressure registered on bicycle saddles that have nonplanar surfaces. As a result, some portion of the pressure registered on the sensors of the mat assumed to be in the perineal region of the cyclist may not have created harmful pressure on the pudendal nerves and vasculature. Portions of the inner and anterior thigh make contact with the saddle in concert with the pedaling dynamics, and we were not able to separate the inner/posterior thigh contact pressure from that which was truly pressure in the perineum. This phenomenon is even more likely with the nonprotruding nose saddles that are "rounded-off" at the front where the saddle nose would be present on a traditional saddle. Thus, we believe that the true perineal pressure reported in this study may be over-represented for all saddles, but this over-representation is likely greater with the nonprotruding nose saddles (saddles, B, C, and D) where the inner thigh comes into contact with the rounded front portion of the saddle.

The bicycle ergometer adjustments of saddle height and handlebar position were selected by the individual participants based on their own subjective preference of cycling position. In the evaluation of saddle designs other investigators (Bressel and Larson; 3) have standardized saddle height as a fixed percentage of inseam height. However, the commonly accepted recommendations for optimal saddle height/inseam height ratio have been based on cycling performance using traditional shaped saddles with a protruding nose design. The validity of these recommendations when applied to other radically different saddle designs (such as saddles B, C, and D in the present study) is unknown. For this reason, we chose a method of saddle height selection based on the cyclists' subjective preference and comfort over standardizing saddle height based on the cyclist's anthropometry. Other than body weight, no other anthropometrics were recorded; thus, it is not known whether participants' self-selected saddle heights within saddle group were consistent with respect to anthropometrics such as inseam height.

The design of two of the nontraditional saddles introduced the phenomenon of hammocking, which has been described by Ferguson-Pell and Cardi (6). Hammocking occurs when the pressure sensor mat spans or hammocks over a split, cutout, or discontinuous region of the saddle cushion and the sensor registers pressure on the mat over this region where no cushion material is present underneath. Saddles C and D both had regions of discontinuity of the cushion surface along the midline of the saddle. Saddle C exhibited a region of slight hammocking that is evident in Figure 2c in the region spanning the midline of the saddle where the two cushioned halves of the saddle are split. This hammocking is a measurement artifact relevant to saddles C and D, but not saddle B or the traditional saddle, neither of which had discontinuities in their cushion surface. The hammocking artifact also suggests that the pressures measured in association with the nonprotruding nose saddles (C and D) were overestimated relative to the pressure associated with the traditional saddle, which still exhibited two times greater pressure in the perineal region.

Moes (14) noted that the pressure threshold for decubitus is as low as 7 kPa for long-term pressure on the skin. The average levels of perineal pressure measured in the present study were substantially higher than 7 kPa. The traditional saddle was associated with an average perineal pressure between 34 and 41 kPa. The saddles without protruding noses were associated with an average perineal pressure of approximately 18 kPa. Data presented by Armstrong (2) indicates an exposure duration tolerance of approximately 150 min at 34 kPa. This explains the development of the "saddle sores" often experienced by cyclists after several hours in the saddle.

The present findings in regard to the relationship between degree of protrusion of the saddle nose and perineal pressure are in agreement with studies of Jeong et al. (11) and Schwarzer et al. (18). The latter of these studies revealed an 82.4% reduction in transcutaneous penile oxygen pressure with a traditional racing saddle design and only a 20.3% reduction with a wide saddle without a protruding nose. Jeong et al. (11) revealed a substantially greater decrease in penile blood flow associated with sitting on a saddle with a long narrow nose than with a wide saddle with a lesser protruding nose. These studies and the present study implicate the shape and protrusion of the saddle nose and the resulting distribution of pressure in the perineum in the compression of the vasculature supplying the penis.

The present data do not support the hypothesis that the absence of a saddle nose causes a shift in the distribution of load among the saddle, pedals, and handlebars. However, it is well recognized that the present study considered stationary cycling in which bicycle stability, handling, and maneuverability were not relevant. Anecdotal reports from police patrol officers and recreational cyclists suggest that the absence of a protruding nose may adversely affect bicycle handling and maneuverability. Future studies should be based on road cycling to consider handling and maneuverability issues in the evaluation of the effectiveness of saddle designs. A longitudinal intervention study is also needed to demonstrate the benefit of saddles without a protruding nose.

We conclude that bicycle saddle designs without a narrow protruding nose significantly reduced pressure distributed in the perineal region of the cyclist during stationary cycling. Based on previous work that indicated a relationship between pressure on the saddle nose and the quality of nocturnal erectile tumescence (16), this reduction in perineal pressure is believed to reduce the risk of erectile problems associated with occupational cycling.

Future work will examine the benefits of saddles without narrow protruding noses in a prospective longitudinal study design in which the cyclists use these saddles in actual road cycling over a longer study period. The longitudinal study design is critical in demonstrating the health benefits of saddles without protruding noses and in determining cyclists' acceptance of these saddle designs. Evaluations of the effect of nonprotruding nose saddle designs on bicycle maneuverability, handling, stability, and weight distribution should be conducted in actual road cycling.

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REFERENCES

1. Andersen, K. V., and G. Bovin. Impotence and nerve entrapment in long distance amateur cyclists. *Acta Neurol. Scand.* 95:233–240, 1997.
2. Armstrong, T. J. Mechanical considerations of skin in work. *Am. J. Ind. Med.* 8:463–472, 1985.
3. Bressel, E., and B. J. Larson. Bicycle seat designs and their effect on pelvic angle, trunk angle, and comfort. *Med. Sci. Sports Exerc.* 35:1–6, 2003.
4. Desai, K. M., and J. C. Gingell. Hazards of long distance cycling. *Br. J. Med.* 298:1072–1073, 1989.
5. Dickson, T. B. Preventing overuse cycling injuries. *Physician Sportsmed.* 13:116–123, 1985.
6. Ferguson-Pell, M., and M. D. Cardi. Prototype development and comparative evaluation of wheelchair pressure mapping systems. *Assistive Technol.* 5:78–91, 1993

7. Goldstein, I. Editorial commentary. *J. Androl.* 23:757–758, 2002.
8. Goodson, J. D. Pudendal neuritis from biking. *N. Engl. J. Med.* 304:365, 1981.
9. Groenendijk, M. C., H. C. C. M. Christiaans, and C. M. J. van Hulten. Sitting comfort on bicycles. In: *Contemporary Ergonomics*, E. J. Lovesey (Ed.). Proceedings of the Ergonomic Society's 1992 Annual Conference, Washington, DC: Taylor and Francis, 1992, pp. 551–557.
10. Hershfield, N. B. Pedaller's penis. *Can. Med. Assoc. J.* 128:366–367, 1983.
11. Jeong, S. J., K. Park, J. D. Moon, and S. B. Ryu. Bicycle saddle shape affects penile blood flow. *Int. J. Impot. Res.* 14:513–517, 2002.
12. Marceau, L., K. Kleinman, I. Goldstein, and J. Mckinlay. Does bicycling contribute to the risk of erectile dysfunction? Results from the Massachusetts Male Aging Study (MMAS). *Int. J. Impot. Res.* 13:298–302, 2001.
13. Mellion, M. B. Common cycling injuries management and prevention. *Sports Med.* 11:52–70, 1991.
14. Moes, C. C. M. The development of a pressure distribution measuring device for various person-product contact areas. In: *Contemporary Ergonomics*, E. D. Megaw (Ed.). Proceedings of the Ergonomic Society's 1989 Annual Conference. New York: Taylor and Francis, 1989, pp. 349–354.
15. Oberpenning, F., S. Roth, D. B. Leusmann, H. van Ahlen, and L. Hertle. The Alcock syndrome: temporary penile insensitivity due to compression of the pudendal nerve within the Alcock canal. *J. Urol.* 151:423–425, 1994.
16. Schrader, S. M., M. J. Breitenstein, J. C. Clark, B. D. Lowe, and T. W. Turner. Nocturnal penile tumescence and rigidity testing in bicycling patrol officers. *J. Androl.* 23:927–934, 2002.
17. Schwarzer, U., W. Wiegand, A. Bin-Saleh, et al. Genital numbness and impotence rate in long distance cyclists. *J. Urol.* 161(Suppl.):178, 1999.
18. Schwarzer, U., F. Sommer, T. Klotz, C. Cremer, and U. Engelmann. Cycling and penile oxygen pressure: the type of saddle matters. *Eur. Urol.* 41:139–43, 2002.
19. Silbert, P. L., J. W. Dunne, R. H. Edis, and E. G. Stewart-Wynne. Bicycling induced pudendal nerve pressure neuropathy. *Clin. Exp. Neurol.* 28:191–196, 1991.
20. Solomon, S., and K. G. Kappa. Impotence and bicycling: a seldom-reported connection. *Postgrad. Med.* 81:99–102, 1987.
21. Sommer, F., D. Konig, C. Graft, et al. Impotence and genital numbness in cyclists. *Int. J. Sports Med.* 22:410–413, 2001.
22. Weiss, B. D. Clinical syndromes associated with bicycle seats. *Clin. Sports Med.* 13:175–186, 1994.