

Protection from scrotal hyperthermia in laptop computer users

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Objective: To evaluate methods of prevention of scrotal hyperthermia in laptop computer (LC) users.

Design: Experimental study.

Setting: University hospital.

Patient(s): Twenty-nine healthy male volunteers.

Intervention(s): Right and left scrotal temperature and LC and lap pad temperatures were recorded during three separate 60-minute sessions using a working LC in a laptop position: session 1, sitting with closely approximated legs; session 2, sitting with closely approximated legs with a lap pad below the working LC; and session 3, sitting with legs apart at a 70° angle with a lap pad below the working LC.

Main Outcome Measure(s): Scrotal temperature elevation.

Result(s): Scrotal temperature increased significantly regardless of leg position or use of a lap pad. However, it was significantly lower in session 3 (1.41°C ± 0.66°C on the left and 1.47°C ± 0.62°C on the right) than in session 2 (2.18°C ± 0.69°C and 2.06°C ± 0.72°C) or session 1 (2.31°C ± 0.96°C and 2.56°C ± 0.91°C). A scrotal temperature elevation of 1°C was reached at 11 minutes in session 1, 14 minutes in session 2, and 28 minutes in session 3.

Conclusion(s): Sitting position with closely approximated legs is the major cause of scrotal hyperthermia. Scrotal shielding with a lap pad does not protect from scrotal temperature elevation. Prevention of scrotal hyperthermia in LC users presently is not feasible. However, scrotal hyperthermia may be reduced by a modified sitting position (legs apart) and significantly shorter use of LC. (Fertil Steril® 2011;95:647–51. ©2011 by American Society for Reproductive Medicine.)

Key Words: Scrotal hyperthermia, laptop computers, spermatogenesis

Testicular function is temperature dependent and requires a temperature 2°C to 4°C below core body temperature (1–3). In humans, scrotal temperature is highly correlated with testicular temperature (4, 5). The negative effect of exogenous scrotal heat exposure on spermatogenesis has been demonstrated by numerous experimental human and animal studies (3, 6). Scrotal hyperthermia is a well-documented mechanism of abnormal spermatogenesis in common diseases associated with male infertility (e.g., varicocele and undescended testis) (7–11). Scrotal heat stress has also been linked to occupational exposure to high temperatures and certain lifestyle factors, including use of disposable plastic-lined diapers in children, prolonged car driving, heated car seats, daily activities, sedentary work, posture, and clothing (12–18).

Local scrotal exposure to actively generated heat is an unusual daily life experience. Scrotal hyperthermia produced by a direct heat source has been studied by various experimental methods, including scrotal insulation, scrotal hot water bath, and direct heating with a 150-W electric light bulb (19–21). Only recently, however,

has the widespread use of the laptop computer (LC) made presence of a heat source close to the scrotum a common event. The LC is an active heat-generating device that, in a laptop position, exposes the scrotum to the dissipated high internal operating temperature of the machine. A working LC in a laptop position causes significant scrotal temperature elevation by a direct heating effect of the LC but also by the dependent sitting position, with closely approximated thighs, that is necessary to balance an LC on the lap (22).

Because LCs are widely used by young men of reproductive age, the prevention of scrotal hyperthermia in this population is important, to avoid potentially negative effects on future fertility. However, protection from scrotal hyperthermia in LC users has not been investigated to date.

The aim of our study was to evaluate the protective effect of a modified sitting position and mechanical shielding of the scrotum from LC-generated heat on rising scrotal temperature in LC users.

MATERIALS AND METHODS

Twenty-nine healthy male volunteer aged 21–35 years (median, 25 years) were recruited. All subjects completed the study. The study was approved by the Institutional Review Board of State University of New York at Stony Brook and conducted at the General Clinical Research Center. All men signed an informed consent form, completed a health questionnaire, and underwent a physical examination. Exclusion criteria were history or presence of varicocele, cryptorchidism, scrotal surgery, skin disease, infertility, testicular size discrepancy, recent febrile illness, and prolonged or occupational exposure to heat. (e.g., sauna or hot bath users, professional drivers, workers exposed to high temperature).

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Shielding of the scrotum from direct LC-generated heat was attempted with randomly used different types of commercially available lap pads with surface area larger than the LC. These lap pads have been advertised and designed to protect the LC from internal overheating and skin from the uncomfortable hot LC surface.

The effect of the legs' position on scrotal temperature elevation was studied in a typical-for-LC-users sitting position with closely approximated legs and in a sitting position with legs apart. The maximum comfortable angle for sitting with legs apart while holding a lap pad was measured and found to be approximately 70° in all participants. It is well correlated with previous studies investigating posture effect (16, 23). Legs position at this angle was supported and maintained by a specially made rectangular wooden box positioned on the floor between the legs.

Two different brands of Pentium 4 (Intel, Santa Clara, CA) LC were used randomly. The LC was turned on for 15 minutes before being positioned on the lap. Each participant spent approximately 15 minutes standing in the room to adjust to the room temperature before being seated in a chair.

Three 1-hour sessions of scrotal temperature measurements were performed on different days in the same room, with the room temperature automatically maintained by thermostat (21.9°C–22.6°C, median temperature 22.4°C). Sessions were conducted at the same time of the day between 8:00 AM and 4:00 PM. Men were dressed in similar casual attire for each session. Body temperature was taken orally before each session using the IVAC Temperature Plus II measurement system (San Diego, CA). The scrotal temperature measurements were performed with a four-channel digital thermometer/datalogger HH309 with four Type K Thermocouple Inputs (Omega Engineering, Stamford CT; resolution 0.1°C/0.1°F) and SC-GG-K-30-36 thermocouples (perfluoroalkoxy [PFA] insulated; Omega Engineering). The scrotal baseline temperature was recorded initially before positioning of the LC or lap pad. The temperature was then recorded automatically at 1-minute intervals to internal memory with subsequent transfer to a personal computer.

Session 1: Working LC/Closely Approximated Legs

Participants adopted a sitting position with closely approximated thighs, necessary to comfortably balance a working LC. This position was strictly maintained throughout the complete session. Two thermocouples were attached to the unshaved scrotal skin anteriorly, corresponding to the right and left testis using thin transparent tape to cover the sensor end of the thermocouple. The third thermocouple was attached to the central bottom surface of the LC. Temperatures of the scrotum and LC were recorded.

Session 2: Working LC/Lap Pad/Closely Approximated Legs

Participants maintained the same sitting position, but the LC was placed on a lap pad. Three thermocouples were attached as in session 1. An additional thermocouple was attached to the central bottom surface of the lap pad. Temperatures of the scrotum, LC, and lap pad were recorded.

Session 3: Working LC/Lap Pad/Legs Apart at 70° Angle

Participants adopted a sitting position with legs spread apart at a 70° angle. The rectangular wooden box was positioned on the floor between the legs to provide continuous legs support at the 70° angle. The LC was placed on a lap pad. This below-the-knee box had no contact with the lap pad. Temperatures of the scrotum, LC, and lap pad were recorded.

Statistical Analysis

Statistical analysis of the data was performed with SAS 9.2 (SAS Institute, Cary, NC). Statistical significance was determined with two-tailed tests, and a *P* value of < .05 was considered significant. The data are expressed as means ± SD. For a simultaneous test, Bonferroni correction was made to adjust the significance level. The Kolmogorov–Smirnov test was used to check whether the data were normally distributed. A two-sample *t*-test was used for comparison of mean temperatures between two independent samples, and a paired *t*-test was used for the change in mean temperatures in each group.

RESULTS

Median body temperature for both sessions was 37°C (range, 36.78°C–37.01°C).

Scrotal Temperature

Table 1 shows scrotal temperatures from all sessions. Scrotal baseline temperature was not significantly different among all three sessions (*P* = .243 on the right and *P* = .987 on the left). The scrotal temperature elevation in 60 minutes was significant in all three sessions (*P* < .001).

Effect of Lap Pad

The effect of a lap pad on scrotal temperature was analyzed by comparing scrotal temperature elevation in men sitting with closely approximated legs with working LC and without a lap pad (session 1) and in men with the same leg position but using a lap pad (session 2). A *P* value of .008 was considered significant after Bonferroni correction. Although scrotal temperature elevation was lower in men using a lap pad, the difference (session 1 vs. 2) was not statistically significant (0.13°C ± 1.07°C, *P* = .542 on the left and 0.50°C ± 1.00°C, *P* = .013 on the right).

In men sitting with legs closed, scrotal temperature rose by 1°C in 11 minutes (right hemiscrotum) and 12 minutes (left hemiscrotum) without a lap pad and in 15 and 13 minutes, respectively, with use of a lap pad (Fig. 1).

LC Temperature

Laptop computer and lap pad temperatures from all session are shown in Table 2. The LC temperature in 60 minutes rose

TABLE 1

Scrotal temperature.

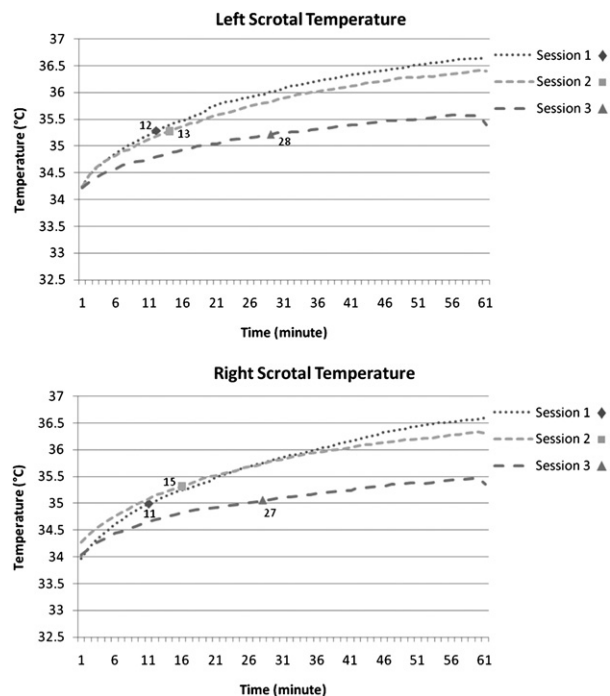
| Variable | Session 1 | | Session 2 | | Session 3 | |
|---------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | Left testis | Right testis | Left testis | Right testis | Left testis | Right testis |
| Scrotal baseline T | 34.25 ± 1.10 | 33.97 ± 1.06 | 34.23 ± 1.05 | 34.28 ± 0.92 | 34.22 ± 0.89 | 34.03 ± 0.96 |
| Scrotal T in 60 min | 36.56 ± 0.74 | 36.53 ± 0.57 | 36.41 ± 0.78 | 36.34 ± 0.66 | 35.63 ± 0.77 | 35.50 ± 0.71 |
| Scrotal T elevation | 2.31 ± 0.96 | 2.56 ± 0.91 | 2.18 ± 0.69 | 2.06 ± 0.72 | 1.41 ± 0.66 | 1.47 ± 0.62 |
| <i>P</i> value | < .001 | < .001 | < .001 | < .001 | < .001 | < .001 |

Note: Temperatures (T) are given as °C; values are shown as mean ± SD. Session 1: working LC/closely approximated legs; session 2: working LC/lap pad/closely approximated legs; session 3: working LC/lap pad/legs apart at a 70° angle.

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FIGURE 1

Rising scrotal temperature in laptop computer users.



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significantly in all three sessions ($P < .001$). However, LC temperature elevation was significantly lower in men using a lap pad (sessions 2 and 3) than in men without a lap pad (session 1). The difference in LC temperature elevation between session 1 and session 2 ($4.55^{\circ}\text{C} \pm 5.30^{\circ}\text{C}$) and between session 1 and session 3 ($4.70^{\circ}\text{C} \pm 4.91^{\circ}\text{C}$) was statistically significant ($P < .001$, with a significance level of $P = .017$ after Bonferroni correction).

Lap Pad Temperature

The lap pad bottom surface temperature increased significantly in sessions 2 and 3. Nevertheless, it remained consistently lower than either the scrotal or LC temperature in all sessions.

In summary, a lap pad significantly lowers working LC temperature while maintaining its own low and comfortable bottom surface

temperature. However, it does not significantly reduce scrotal temperature elevation.

Effect of Posture

Scrotal temperature The effect of sitting posture on scrotal temperature was evaluated by comparing scrotal temperature elevation in men sitting with closely approximated legs with and without a lap pad and in men using a lap pad and sitting with legs apart at a 70° angle. Scrotal temperature elevation was significantly lower in men sitting with legs apart (session 3) than in men sitting with legs closed, regardless of lap pad use (sessions 1 and 2) (Table 1). The difference in scrotal temperature elevations was significant between session 3 and session 1 ($0.90^{\circ}\text{C} \pm 1.10^{\circ}\text{C}$ on the left and $1.09^{\circ}\text{C} \pm 1.10^{\circ}\text{C}$ on the right, $P < .001$) as well as between session 3 and session 2 ($0.77^{\circ}\text{C} \pm 0.87^{\circ}\text{C}$ on the left and $0.59^{\circ}\text{C} \pm 0.82^{\circ}\text{C}$ on the right, $P < .001$), with a significance level of $P = .008$ after Bonferroni correction.

In men using a lap pad and sitting with legs closed, scrotal temperature rose by 1°C in 15 minutes (right hemiscrotum) and 13 minutes (left hemiscrotum), whereas the same temperature elevation was reached in 27 and 28 minutes, respectively, in men sitting with legs apart (Fig. 1).

LC temperature The LC temperature elevation in men using a lap pad (sessions 2 and 3) was not significantly different in men sitting with legs closed vs. with legs apart ($0.16^{\circ}\text{C} \pm 4.51^{\circ}\text{C}$, $P = .854$, with a significance level $P = .017$ after Bonferroni correction) (Table 2).

Lap pad temperature The lap pad temperature elevation in men sitting with legs apart at a 70° angle (session 3) was lower than in men sitting with closely approximated legs (session 2). The difference in lap pad temperature elevation was statistically significant ($1.57^{\circ}\text{C} \pm 2.81^{\circ}\text{C}$, $P = .006$) (Table 2).

In summary, a sitting position with legs apart at a 70° angle significantly lowers scrotal temperature and bottom surface lap pad temperature but not LC temperature in men using a lap pad.

DISCUSSION

Spermatogenesis is a temperature-dependent process requiring temperature lower than that of the body, and it can be disrupted by scrotal hyperthermia (24–27). Scrotal temperature may be influenced by many factors including changes in core body temperature, countercurrent heat exchange between pampiniform plexus and testicular artery, thermal difference between scrotal skin and perigenital air, and rapidity of perigenital air exchange (15, 23, 25). Overall, many animal and human studies have suggested a negative effect of scrotal hyperthermia on spermatogenesis. Multiple

TABLE 2

Laptop and lap pad temperature.

| Variable | Laptop computer | | | Lap pad | |
|-------------|------------------|------------------|------------------|------------------|------------------|
| | Session 1 | Session 2 | Session 3 | Session 2 | Session 3 |
| Starting T | 31.63 ± 2.58 | 30.99 ± 2.99 | 30.80 ± 2.39 | 26.40 ± 2.00 | 26.19 ± 1.54 |
| T in 60 min | 41.13 ± 1.90 | 35.94 ± 2.73 | 35.59 ± 2.55 | 32.91 ± 3.10 | 31.14 ± 2.62 |
| T elevation | 9.50 ± 3.25 | 4.95 ± 4.10 | 4.79 ± 3.41 | 6.52 ± 2.66 | 4.95 ± 2.80 |
| P value | $< .001$ | $< .001$ | $< .001$ | $< .001$ | $< .001$ |

Note: Temperatures (T) are given as $^{\circ}\text{C}$; values are expressed as mean \pm SD. Session 1: working LC/closely approximated legs; session 2: working LC/lap pad/closely approximated legs; session 3: working LC/lap pad/legs apart at a 70° angle.

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underlying molecular mechanisms of testicular thermosensitivity have been implicated, including hypoxia, oxidative stress, heat-induced germ cell apoptosis, and deterioration of spermatozoal DNA integrity (28, 29).

Scrotal temperature in infertile men is significantly higher than that observed in fertile men (14, 30). Scrotal hyperthermia was shown to be associated with more or less severely impaired semen quality in men, including azoospermia, oligoasthenospermia, and teratozoospermia (6, 14, 30–35). Conversely, scrotal cooling improved sperm quantity and quality (36–39). Warming of the testis has been proposed as a method of contraception (33, 40). Although more well-designed and controlled studies are still necessary to separate direct from circumstantial evidence of the effect of genital heat stress in humans, the few presently available human and animal data demonstrate a negative impact of genital hyperthermia on semen quality (6). Thonneau et al. concluded that male heat exposure must be considered as a significant risk factor for male infertility (2). Therefore, scrotal protection from high temperature impact is important.

Laptop computers have become an integral part of the modern lifestyle, especially in the younger population of reproductive age. They are being used widely by teenagers and even preschool boys with still-developing spermatogenesis. In 2008 it was estimated that 145.9 million notebook computers were sold, and in 2009 the number will grow to 177.7 million (41). The LC produces significant transient but repetitive scrotal hyperthermia for years. Insufficient recovery time/cooling period between heat exposures may cause irreversible or partially reversible changes in male reproductive function (5).

The magnitude of scrotal hyperthermia associated with abnormal spermatogenesis is not established. Although an increase in scrotal temperature of 1°C was sufficient to suppress spermatogenesis in some studies, others did not confirm those findings when scrotal temperature rose by 0.8°C–1°C (19, 42). Higher testicular or scrotal temperature elevation between 1°C and 2.9°C was more consistently associated with a sustained and considerable negative effect on spermatogenesis and fertility (7, 21, 43, 44). For that reason, a scrotal temperature increase of more than 1°C above baseline has been suggested as a possible minimal thermal gradient capable of inhibiting spermatogenesis (13, 42). Therefore, maintaining scrotal temperature elevation within a 1°C margin can serve as a reasonable protective goal.

Protection from scrotal hyperthermia in LC users must address both causative factors—direct heat exposure and sitting position with closely approximated legs—to reach a cumulative effect of lowering scrotal temperature.

The lap pad significantly lowered external bottom surface LC temperature of the working LC while maintaining its own low bottom surface temperature. Such reduction of convective and conductive scrotal heat exposure, however, had only an insignificant effect on scrotal temperature elevation if men were sitting in a usual LC-dependant position with closely approximated legs (2.31°C ± 0.96°C vs. 2.18°C ± 0.69°C on the left and 2.56°C ± 0.91°C vs. 2.06°C ± 0.72°C on the right). Scrotal temperature reached the 1°C limit at almost the same time with or without a lap pad (11 and 14 minutes, respectively).

Conversely, elimination of a second local thermal factor—legs position—by sitting with legs apart at a 70° angle significantly lowered scrotal temperature elevation (2.31°C ± 0.96°C vs. 1.41°C ± 0.66°C on the left and 2.56°C ± 0.91°C vs. 1.47°C ± 0.62°C on the right). In men using a lap pad and sitting with legs apart, scrotal temperature rose by 1°C in 28 minutes. This finding corroborates

our previous study, which indicated a much smaller impact of direct LC-generated heat on scrotal temperature elevation compared with the dependant posture (22).

Effect of legs position on scrotal temperature has been previously studied (16, 19, 23). Lower scrotal temperature was noticed when the thighs were widely separated than when they were approximated to the scrotum. A significant difference (1.64°C) was found between scrotal temperature measured sitting with thighs at an angle of 70° and those measured sitting with thighs together (23). Such a position was recommended to paraplegic men wishing to be fertile. A 70° angle was considered large and not convenient to maintain for a long time in everyday life, but a smaller angle may not have such a beneficial effect. A significantly lower (up to 3°C) scrotal temperature was found in men sitting on the saddle chair with supported knee angle of 135° than in men sitting on commonly used chairs (45). Significantly higher (0.8°C–0.9°C) scrotal temperatures were documented after 15 minutes in a seated position with legs crossed than in a seated position with legs apart at an angle of 70° (16). It was concluded that such a purely local thermal effect of sitting with legs closed is due to reduction of the interface between the scrotum and the external environment, with lower air convection, and large surface contact between the scrotum and thighs. It is possible that in this position scrotal temperature reaches a physiological threshold value, and further increase is unlikely if other regulatory protective mechanisms are functional (16). Otherwise, supraphysiologic elevation of scrotal temperature occurs, with potential impact on spermatogenesis depending on the time spent seated with legs crossed.

Our study showed that scrotal temperature elevation is determined mostly by sitting with closely approximated thighs, which is absolutely necessary to use an LC on the lap. As such, scrotal hyperthermia in LC users is the universal phenomenon, with minimal influence of make, model, heat-generating capacity, size of LC, or use of any kind of presently available lap pads. In fact, smaller lap pads and notebook/netbook computers will require even closer legs approximation to hold the LC conveniently on the lap.

In men using a lap pad and sitting with legs apart at a 70° angle scrotal temperature was still elevated by more than 1°C, indicating insufficient preventive effect. Our study indicates that scrotal temperature elevation may be kept below the “safe” level of 1°C only by short-term use of LC in a laptop position (less than 11 or 28 minutes, depending on use of lap pad and legs position). With significantly longer average daily and repetitive use of LC, prevention of scrotal temperature elevation above 1°C is not feasible. However, maximum reduction of scrotal hyperthermia remains an important goal because the negative impact of scrotal temperature on sperm concentration was found to be incremental (14).

In conclusion, our study demonstrates that the dependent sitting position with closely approximated legs is the major cause of scrotal hyperthermia in LC users. Scrotal shielding with a lap pad alone can reduce LC overheating and protect skin from the uncomfortable heat effect but cannot prevent scrotal temperature elevation and may provide a false sense of protection to LC users. Prevention of scrotal hyperthermia presently is not feasible. However, scrotal hyperthermia can be minimized by a modified sitting position (legs apart) and/or shorter use of the LC. New protective methods/devices simultaneously addressing LC-generated heat exposure and dependant legs position must be sought for safer use of LCs. Because LCs are widely used by teenage boys and young men of reproductive age, further well-designed and controlled studies are warranted to evaluate the impact of LC-related scrotal heat stress on testicular function and fertility.

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