Clinical characteristics and outcomes of exertional rhabdomyolysis after indoor spinning: a systematic review

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Abstract

Objectives: An increasing number of patients are diagnosed with exertional rhabdomyolysis secondary to indoor spinning. We performed a systematic review to characterize the clinical features of this new clinical entity.

Methods: We conducted a thorough literature search on PubMed, Embase, Web of Science, Scopus, and The Cumulative Index to Nursing and Allied Health Literature (CINAHL). Articles published from inception to 23 June 2021 were considered. A two-stage article selection process was performed. Articles that reported clinical characteristics and outcomes in patients with spin-induced exertional rhabdomyolysis (SIER) were included. Quality assessment was performed using the Joanna Briggs Institute checklists.

Results: There were a total of 22 articles and 97 patients with SIER. Most patients were healthy females who had attended their first spinning session. The mean time to clinical presentation was 3.1 ± 1.5 days. The most common presenting symptoms were myalgia, dark urine, and muscle weakness in the thighs. Seven patients (7.2%) developed acute kidney injury, and two patients (2.1%) required temporary inpatient hemodialysis. Four patients (4.1%) developed thigh compartment syndrome and required fasciotomies. No long-term sequelae or mortality were observed. The mean length of stay was 5.6 ± 2.9 days.

Conclusions: Healthcare professionals must have a high index of suspicion for SIER when a patient presents with myalgia, dark urine, or weakness after a recent episode of indoor spinning. Fitness center owners, spinning instructors, and participants should also be better educated about the clinical features and manifestations of SIER.

1. Introduction

Indoor spinning is a high-intensity indoor physical activity offered in many gyms [1,2]. During each spinning session, participants cycle on modified stationary bikes under the guidance of an instructor and with musical accompaniment. The intensity of each spin session is closely related to changes in position, pedal resistance, music rhythm, and cadence. Participants can adjust the pedal resistance to mimic either cycling on a flat road or against a positive incline. Due to its easy accessibility and purported health benefits [2–4], spinning has gained wide popularity among the general public and has become a fast growing fitness trend, especially in the past decade. According to survey data from the United Kingdom, spinning classes were the third most popular group exercise among adults, with an estimated 745,000 participants in 2018 alone [5]. Similarly, data from the American College of Sports Medicine ranked group exercise activities such as spinning classes as the third most popular global fitness trend of 2020 [6].

As the popularity of spinning increases, so does the number of people who get injured while spinning [7,8]. One of the most serious complications of spinning is the development of exertional rhabdomyolysis (ER), typically defined as the development of muscle-related symptoms and a significant elevation in creatine kinase (CK) with or without myoglobinemia or myoglobinuria following prior exercise [9]. ER, which occurs after spinning, is specifically referred to as spinning-induced ER (SIER). SIER is a relatively new clinical entity that is emerging as a leading cause of ER at some hospitals [10]. Although ER is typically associated with extreme or endurance sports such as marathon running, it is interesting to note that spinning has similarly led to ER in young and healthy individuals [10–12].

The recent increase in patients diagnosed with SIER is an interesting phenomenon that could be due to several reasons. Firstly, individuals with varying fitness levels can participate in spinning because it is easily accessible and the barrier to entry...
is low. Secondly, the high-intensity and repetitive nature of spinning may promote the development of SIER [13,14]. In addition, the group-based nature of SIER may increase individual motivation during the activity, resulting in over-exertion [15]. Finally, the environment that spinning is often conducted in, which usually involves loud rhythmic music, may also induce increased exertion and decrease the level of perceived exhaustion [16].

Similar to other causes of ER, SIER may present as a classical triad of myalgia, dark-colored urine, and weakness [17]. However, only a small proportion of patients with SIER present with the classic triad of symptoms. In most patients, the symptoms can be varied. If not diagnosed and treated promptly, SIER can lead to serious sequelae such as compartment syndrome and acute kidney injury (AKI). Given the increasing popularity of spinning, there is an urgent need to better characterize this new clinical entity. Therefore, we conducted a systematic review to consolidate the current literature and better characterize the clinical features and outcomes of SIER.

2. Materials and methods

This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [18] and Meta-Analyses and Systematic Reviews of Observational Studies (MOOSE) guidelines [19]. This review is registered in the International Prospective Register of Systematic Reviews (PROSPERO) (CRD42021262637) [20].

2.1 Search strategy

Our search strategy was developed in consultation with a medical information specialist. We utilized the MeSH term ‘rhabdomyolysis’ and the non-MeSH terms ‘rhabdomyolysis, myoglobin, myoglobinemia, myoglobinuria, muscle breakdown, muscle death, spin, spinning, cycle, cycling, indoor cycle, indoor-cycling, indoor cycling, indoor-cycling.’ We performed an exhaustive literature search without any language restrictions with these search terms in five bibliographic databases: PubMed, EMBASE, Web of Science, Scopus and The Cumulative Index to Nursing and Allied Health Literature (CINAHL). We ensured that we included all possible relevant literature by performing backward reference searching of included studies and published review articles. Our search strategy can be found in the Appendix.

2.2 Selection criteria

We included all descriptive and comparative observational studies including case-control studies, case series, and case reports that had reported clinical characteristics and outcomes of patients presenting with SIER published from inception till 23 June 2021. We defined SIER as patients who developed ER after participating in an instructor-led group-based stationary cycling session, usually conducted in an indoor setting. We excluded studies that described patients presenting with ER from similar exercises such as outdoor cycling or individual indoor gym cycling. We also excluded conference abstracts, commentaries, review articles, and articles where full-text was not available after correspondence with the authors. We ensured that there was no overlapping or repeated data. We used the web-based platform Rayyan QCRI [21] to perform article deduplication, screening, and final eligibility assessment. Two authors (YM and JJN) performed the literature search and independently assessed the eligibility of the studies. Any disagreements in study selection were arbitrated by consensus with a third author (AMTLC).

2.3 Data extraction

An author (JJN) extracted data from the included studies into a pre-specified data collection form. The data was cross-checked and validated by another author (YM) for any discrepancies. We extracted the following data – (i) study characteristics including first author details, year of publication, study origin, study design and sample size; (ii) patient characteristics including age, gender, body mass index, significant past medical history, spin class attendance history and spin class duration; (iii) clinical characteristics such as time to presentation, presenting symptoms, physical examination findings, and relevant laboratory values; and (iv) patient outcomes such as length of stay, complications and sequelae. If the data presented was unclear, we contacted the corresponding author by e-mail for clarification.

2.4 Quality assessment

The methodological quality of the included studies was assessed independently by two authors (YM and JJN) using the Joanna Briggs Institute (JBI) critical appraisal tool [22]. For individual case reports, we utilized the case reports critical appraisal checklist which comprised of eight domains [23]. For case series and case-control studies, we utilized the case series critical appraisal checklist which comprised of ten domains [22]. These domains serve to assess the internal validity and risk of bias of each included study. Case-control studies were assessed using the case series appraisal tool as only data from the SIER arm was relevant in this systematic review.

2.5 Statistical analysis

Due to the small sample size of each study, we did not perform formal weighted pooling of data such as meta-analysis of proportions or means due to the risk of bias caused by sampling error. We only utilized simple statistical methods to report non-weighted combined proportions and means for relevant categorical and continuous outcomes. For categorical outcomes, we obtained the non-weighted combined proportions by simple arithmetic addition of each reported proportion. For continuous outcomes, we used the Cochrane’s method [24] to combine and obtain the average mean values. If studies reported their data as median and interquartile range, we converted them to mean and standard deviation using a validated statistical method [25]. We excluded studies
that did not provide any data or had provided incomplete or inaccurate data from statistical analysis.

3. Results

3.1 Literature retrieval

Our initial search yielded a total of 9463 studies. After removing duplicates, 8475 articles were considered for initial title and abstract screening. After screening, 82 studies remained for full-text review. For seven studies, we were unable to obtain the full text despite contacting the corresponding author. A total of 75 studies underwent full-text review, and finally 22 studies met our inclusion criteria and was included in our systematic review. Our study identification and selection process is illustrated in the PRISMA-P flowchart (Figure 1).

3.2 Study characteristics

Of the 22 studies included, nine studies were from the United States of America [10,12,31–33,38,39,42], five studies were from South Korea [35,36,40,41,43] and two studies were from Italy [26,29]. The remaining six articles were from Australia, Argentina, Israel, Singapore, Turkey and the United Kingdom, respectively [27,28,30,34,37,44]. Sixteen studies were case reports [11,12,26,27,29–34,36–40,42], while three studies were case series comprising between five to eleven patients [28,35,44]. The remaining three studies were retrospective case-control studies which compared clinical characteristics and outcomes between patients with SIER and patients with ER from other etiologies [10,41,43]. All included studies were published between 2003 and 2021, with 19 studies [10–12,29–44] published within the last decade (2011 – present). In the included studies, a total of 97 patients were diagnosed and treated for SIER. Individual patient data were obtained in 20 of the 22 studies, with the exception of the studies by Cutler et al. and Shim et al [10,43]. The characteristics of all included
studies are presented in Table 1, and where appropriate, individual patient data from the studies are summarized and presented.

3.3 Quality assessment

Sixteen studies were assessed using the JBI case report appraisal checklist [11,12,26,27,29–34,36–40,42], while six studies were assessed using the JBI case series appraisal checklist [10,28,35,41,43,44]. A summary of the quality assessment performed for all included studies is provided in the Appendix.

3.4 Patient characteristics

The age of the included patients ranged from 15 to 49 years with a combined mean of 26.7 ± 6.6 years. Of the 19 studies [11,12,26,27,29–42,44] that provided individual patient data, nine (47.4%) patients were between 15 to 19 years of age, 33 (64.7%) patients were between 20 to 29 years of age, and nine (17.6%) patients were 30 years of age and above. All studies provided information on gender, and 74 out of 97 (76.3%) patients were female. Seven studies [12,31,35,36,40,41,43] reported patient body mass index ranging from 18.5 kg/m² to 33.4 kg/m², with a combined mean of 24.4 ± 3.9 kg/m². The vast majority of patients were healthy and had no reported comorbidities. Six patients were reported to have the following comorbidities – hereditary neuropathy with liability to pressure palsy, lower extremity congenital bony anomalies, Gilbert’s syndrome, juvenile myoclonic epilepsy, sickle cell trait and hyperlipidemia, respectively. Nineteen studies [10–12,26–37,39,42–44] with a total of 80 patients provided data about spinning class participation. Of the 80 patients, 67 patients (83.8%) had never participated in a spinning class before and developed SIER after their first spinning session. Data from 12 studies [11,26,29,30,33,34,38–41,43,44] reported that the duration of the spinning session ranged from 15 to 100 minutes, with a combined mean of 53.4 ± 15.7 minutes.

3.5 Clinical presentation

The time interval between the spinning session and onset of symptoms ranged from 0 to 2 days, with a combined mean of 0.8 ± 0.5 days. On the other hand, the time interval between spinning session to clinical presentation at a medical facility ranged from 0 to 5 days, with a combined mean of 3.1 ± 1.5 days. Of the 18 studies [10–12,26,27,30–34,37–44] with individual patient data, 17 (34%) patients presented 48 hours or less after the spinning session, whereas 33 (66%) patients presented after 48 hours. The most commonly reported presenting symptoms were myalgia and dark urine. In the relevant studies, 69.1% of patients reported myalgia and 56.7% reported dark urine [9,23–29,31–34,36,37,39–41]. Only 16.5% of patients reported muscle weakness at initial presentation. Consequently, the most common findings on clinical examination were muscle tenderness, muscle swelling, and reduced power. The most commonly affected muscle group was the thigh (97.7%). A summary of the study and patient characteristics can be found in Table 1.

3.6 Laboratory results

Apart from the study by Mong et al [44], 21 studies [10–12,26–43] reported serum CK levels on initial presentation. CK levels ranged from more than 11,000 to 261,177 U/L and had a combined mean of 80,627 ± 64,774.4 U/L. Six studies [12,29,34–36,43] reported serum myoglobin levels on initial presentation ranging from 1000 to more than 20,000 ng/ml, with a combined mean of 11,154.5 ± 5575.5 ng/ml. Nine studies [26,28–30,34–36,40,41] reported serum lactate dehydrogenase (LDH) levels on initial presentation that ranged from 1446 to 62,970 U/L, with a combined mean of 5246 ± 10,063 U/L. Fourteen studies [12,27,29–32,34–38,40,41,43] reported serum aspartate aminotransferase (AST) levels on initial presentation. The values of AST ranged from 249 to 3380 U/L, with a combined mean of 1121.1 ± 639.9 U/L. Twelve studies [12,27,30,31,34–38,40,41,43] reported serum alanine aminotransferase (ALT) levels on initial presentation, which ranged from 64 to 656 U/L, with a combined mean of 318.2 ± 169.8 U/L. Five studies [31,35,40,41,43] reported serum blood urea nitrogen (BUN) levels on initial presentation ranging from 7.2 to 61.4 mg/dL, with a combined mean of 11.5 ± 7.8 mg/dL. Finally, ten studies [12,26,31,32,35,38,40–43] had reported serum creatinine levels on initial presentation. Creatinine levels ranged from 0.5 to 7.4 mg/dL with a combined mean of 0.9 ± 1 mg/dL. A summary of laboratory testing at initial presentation is provided in Table 2.

3.7 Sequelae and length of stay

All included studies had provided relevant information regarding the complications of SIER. The incidence of acute kidney injury secondary to SIER was 7.8% (7 out of 97 patients). Two of the seven patients with acute kidney injury required temporary inpatient hemodialysis. No patients developed chronic kidney disease or required long-term renal replacement therapy. On the other hand, the incidence of lower extremity compartment syndrome secondary to SIER was 4.1% (4 out of 97 patients). All four patients who developed lower extremity compartment syndrome required emergency fasciotomies. Seventeen studies [10,26–32,34,35,37,39–44] had reported the hospital length of stay (LOS), ranging from 1 to 16 days. The combined mean length of stay was 5.6 ± 2.9 days. A summary of sequelae and length of stay can be seen in Table 3.

4. Discussion

An increasing number of patients are diagnosed with SIER. While there are systematic reviews evaluating other types of ER [45,46], there has been no systematic review of SIER. In our systematic review, we describe the clinical features and outcomes of 97 patients with SIER. We also report several important findings that may have implications in the regulation and conduct of spinning classes.

In this systematic review, we highlighted several important findings. First, data from our systematic review suggests that SIER is a relatively new clinical phenomenon. Most articles (19 of 21) referring to SIER were published within the last decade.
| Author          | Year | Country | Study type | N | Age (years) | Female | BMI (kg/m²) | Comorbidity | First spin | Spin duration (minutes) | Time to symptoms (days) | Time to presentation (days) | Presenting symptoms | Clinical examination | Muscle group |
|-----------------|------|---------|------------|---|-------------|--------|-------------|-------------|------------|------------------------|------------------------|------------------------|---------------------|---------------------|-------------|
| Bertoldo et al. | 2003 | Italy   | CR         | 1 | 49         | 0/1    | NR          | Nil         | 1/1        | 60                     | 0.5                    | 2                     | Y       | Y                  | NR        | NR        | NR        | NR        | Thigh      |
| Young et al.    | 2004 | UK      | CR         | 1 | 34         | 1/1    | NR          | Nil         | 1/1        | 0                      | 2                      | Y                     | Y       | Y                  | NR        | NR        | NR        | NR        | Thigh      |
| Montero et al.  | 2009 | Argentina | CS         | 9 | NR         | 8/9    | NR          | Hypothyroidism (1) | 9/9       | NR         | NR         | NR          | Y (9)   | Y (5)             | NR (4)   | Y (9)     | Y (9)     | NR (9)    | Y (9)     | NR (9)    | Thigh      |
| Bonsi et al.    | 2011 | Italy   | CR         | 1 | 19         | 1/1    | NR          | Nil         | 1/1        | 45                     | 0.5                    | NR                    | Y       | Y                  | Y         | Y         | Y         | Y         | NR         | NR        | Thigh      |
| Benish et al.   | 2012 | Israel  | CR         | 1 | 21         | 1/1    | NR          | Heereditary neuropathy | 1/1       | 45                     | 0                      | 5                     | Y       | Y                  | Y         | Y         | NR        | Y         | Y          | Thigh      |
| Parmar et al.   | 2012 | USA     | CR         | 2 | 32 ± 8.5   | 2 (6–38) | 1/2        | Nil         | 2/2        | 30 ± 4.8 (26.6–33.4) | 1.5 ± 0.7 (1–2) | 3         | Y (2)   | Y (2)             | NR (2)   | Y (2)     | Y (2)     | Y (1)     | Y (1)     | NR (1)    | Thigh (2) |
| DiFilippis et al. | 2014 | USA     | CR         | 2 | 24         | 1/2    | NR (2)      | Lower limb deformity (1) | 2/2       | NR (2)     | NR (2)     | 3 ± 1.4 (2–4) | Y (2)   | Y (2)             | NR (2)   | Y (1)     | N (1)     | Y (1)     | NR (1)    | Thigh (2) |
| Cutler et al.   | 2015 | USA     | CCS        | 14| 29         | 6/14   | NR          | Hyperlipidemia (1) | 12/14     | NR         | NR         | 3 (2–8)     | NR       | NR                 | NR       | NR       | NR        | NR       | NR        | NR       | Thigh (14) |
| Eckner et al.   | 2015 | USA     | CR         | 1 | 42         | 0/1    | NR          | Nil         | 1/1        | 45                     | 0                      | 2                     | NR       | Y                  | NR       | NR       | NR        | NR       | NR        | NR       | Thigh      |
| Fidan et al.    | 2015 | Turkey  | CR         | 1 | 26         | 1/1    | NR          | Nil         | 1/1        | 30                     | 5                      | Y                     | N       | N                  | Y         | Y         | N         | NR        | Thigh      |
| Kim et al.      | 2015 | South Korea | CS         | 11| 23.2 ± 8.3 | 15–39 | 11/11      | Nil         | 11/11      | 23.9 ± 2.6 (19.6–28.0) | 1.1                  | Y (1)     | Y (11)  | Y (11)             | NR (11)  | Y (11)    | Y (11)    | Y (11)    | Thigh (11) |
| Ryu et al.      | 2015 | South Korea | CR         | 1 | 29         | 1/1    | 25          | Nil         | 0/1        | NR         | 2          | NR         | Y       | Y                  | NR       | NR       | Y         | NR        | Thigh      |
| Beavis et al.   | 2016 | Australia | CR         | 1 | 19         | 1/1    | NR          | Nil         | 1/1        | NR         | 5          | Y         | Y       | Y                  | NR       | NR       | NR        | NR       | Thigh      |
| Brogan et al.   | 2016 | USA     | CR         | 3 | 28.7 ± 7.5 | 20–33 | 2/3        | NR          | 2/3        | 15 (1)     | NR (2)     | NR (3)    | 3 ± 1 (2–4) | Y (3)   | Y (3)             | NR (3)   | Y (3)     | NR (3)    | Y (3)     | NR (3)    | Thigh (3) |
| Gould et al.    | 2016 | USA     | CR         | 1 | 19         | 1/1    | NR          | Nil         | 1/1        | 45                     | NR (3)     | 3         | Y       | Y                  | NR       | Y         | NR        | Y         | NR        | Thigh      |
| Jeong et al.    | 2016 | South Korea | CR         | 1 | 21         | 1/1    | 2.45       | Nil         | NR         | 40                     | 2          | Y       | Y                  | Y         | Y         | Y         | Y         | NR        | Thigh      |
| Kim et al.      | 2016 | South Korea | CCS        | 13| 25.7 ± 5.0 | 18–37 | 12/13      | NR          | 12/13      | 23.1 ± 3.6 | 59.2 ± 24.3 (30–100) | 2.4 ± 1.2 (1–4) | NR       | NR                 | NR       | NR       | NR        | NR        | NR        | Thigh (13) |
| Ramme et al.    | 2016 | USA     | CR         | 3 | 26 ± 1.7  | 24–27 | 2/3        | Epilepsy (1) | 3/3       | 26.8 ± 7.3 (18.5–32.2) | 3.3 ± 0.6 (3–4) | Y (3)   | Y (2)             | NR (1)   | Y (3)     | Y (1)     | N (2)     | Thigh (3) |

(Continued)
| Author          | Year | Country     | Study type | N   | Age (years) | Female | BMI (kg/m²) | Comorbidity | First spin | Spin duration (minutes) | Time to symptoms (days) | Time to presentation (days) | Presenting symptoms | Clinical examination | Reduced power | Reduced ROM | Muscle group |
|-----------------|------|-------------|------------|-----|-------------|--------|-------------|-------------|------------|------------------------|------------------------|----------------------------|---------------------|----------------------|--------------|-------------|--------------|
| Hamilton et al. | 2017 | USA         | CR         | 1   | 25          | 1/1    | NR          | Nil         | 1/1        | NR                     | NR                     | 2                          | Y                   | Y                        | Y             | Y           | Y             |
| Shim et al.     | 2018 | South Korea | CCS        | 23  | 28          | 18/23  | 24.4        | Nil         | 14/23      | 60 (50–60)²        | 3 (2–4)²               | Y (21)                     | N (2)                 | N (4)                  | Y             | NR          | NR           |
| Longo et al.    | 2019 | USA         | CR         | 1   | 28          | 1/1    | NR          | Sickle cell trait | 1/1 | 45         | 0.5              | 3                         | Y                     | Y                        | Y             | Y           | Y             |
| Mong et al.     | 2021 | Singapore   | CS         | 5   | 24.4 ± 1.3  | 3/5    | NR          | Nil         | 4/5        | 45 (3–6)¹           | Y (5)                  | Y (4)                     | NR (5)               | NR (5)                | NR (5)       | NR (5)      | Thigh (5)    |
| Combined values | NA   | NA          | NA         | 97  | 26.7 ± 6.6  | 74/97  | 24.4 ± 3.9  | NA          | 67/80      | 53.4 ± 15.7          | 0.8 ± 0.5              | 3.1 ± 1.5                   | 67/80               | 55/97                  | 16/97        | 27/97       | 32/97        | 17/97       | 25/97       | 85/87       |

**Legend:**
- CR: case report
- CCS: case-control study
- NR: not reported

- **Continuous individual patient data is summarized to mean ± standard deviation with minimum and maximum values in parentheses, where applicable.**
- **Data reported as median (range) or median (interquartile range) but converted to mean ± standard deviation (not shown) for pooling using a validated statistical method.**
The recent increase in the number of patients diagnosed with SIER may be associated with the increasing popularity of spinning classes. There are several reasons for the popularity of spinning classes, such as ease of access and low barrier to participation. The number of dedicated spinning studios or fitness facilities offering spinning classes is increasing, possibly due to the lucrative profit margins and good attendance rates. According to recent market research reports, approximately 7000 businesses in the United States offer spinning classes. Also, more than 70% of fitness centers surveyed by the International Health, Racquet and Sportsclub Association (IHRSA) offer spinning classes. In addition, in a survey of 400 spinning participants and instructors, 50% of respondents said they traveled less than 10 minutes to their spinning class. Undoubtedly, factors such as ease of access and convenience of attending a spinning session have contributed to the popularity of spinning classes.

Second, we found that the predominant demographic profile of patients diagnosed with SIER were young adult females with no significant comorbidities, although the incidence of ER tended to be higher in men. This contrasting disparity between the gender profiles of patients with SIER compared to other forms of ER has been reported in several studies [8,10,43,51]. A recent study by Shroff et al. reported that 77% of patients with SIER were female, as compared to only 24% in other forms of ER [51]. Similarly, a study by Shim et al. also reported the gender disparity between SIER and other forms of ER, with 78.3% of SIER patients being female, as compared to 38.5% in other forms of ER [43]. We believe that the reason for this female preponderance is likely to be related to demographic reasons, rather than physiological reasons. In actual fact, females are generally less susceptible to rhabdomyolysis due to physiological factors such as higher circulating levels of estrogen, which may protect against the development of ER by suppressing oxidative stress, reducing the infiltration of inflammatory cells into the muscle, and inhibiting calcium ion release from the sarcoplasmatic reticulum [17,52,53]. Data from the UK Group Exercise National Survey Report revealed that almost 80% of group exercise participants were female [5]. This trend is also confirmed by survey data from Australia, where 76% of individuals who were willing to spend money on exercises.

Table 2. Laboratory results on initial presentation.

| Author        | N   | Creatine kinase (U/L) | Myoglobin (ng/mL) | LDH (U/L) | AST (U/L) | ALT (U/L) | BUN (mg/dL) | Creatinine (mg/dL) |
|---------------|-----|-----------------------|-------------------|-----------|-----------|-----------|-------------|-------------------|
| Bertoldo et al. [26] | 1   | 185,600               | NR                | 8840      | NR        | NR        | NR          | 1.5               |
| Young et al. [27] | 1   | 24,540                | NR                | 3380      | 511       | NR         | NR          | NR                |
| Montero et al. [28] | 9   | 70,933.8 ± 57,810     | NR                | 1750.7 ± 1529.1 | NR        | NR         | NR          | NR                |
| Boni et al. [29] | 1   | 124,698               | 18,488            | 62,970    | 1219      | NR         | NR          | NR                |
| Benish et al. [30] | 1   | 132,170               | 6995              | 1256      | 280       | NR         | NR          | NR                |
| Parmar et al. [31] | 2   | 118,288.5 ± 44,825.6  | NR                | 1808.5 ± 601.7 (1383–2234) | 468 ± 144.2 (366–570) | 14 ± 4.2 (11–17) | NR         | 0.9 ± 0.1 (0.8–1.0) |
| DeFilippis et al. [32] | 2   | 88,255 ± 103,654.8    | NR                | 1117.5 ± 1224 (252–1983) | NR        | NR         | NR          | 0.9 (0.87–0.93)   |
| Cutler et al. [10] | 14  | 73,000*               | NR                | NR        | NR        | NR         | NR          | NR                |
| Eichner et al. [33] | 1   | 80,000                | NR                | NR        | NR        | NR         | NR          | NR                |
| Fidan et al. [34] | 1   | 55,235                | 3984              | 1508      | 974       | 314        | NR          | NR                |
| Kim et al. [35] | 11  | >11,000 (11)*         | 12,081.2 ± 3125.8 (8472–16,849) | 3698.4 ± 1917 (1446–7350) | 1073.5 ± 487.4 (415–2020) | 323.2 ± 153.0 (127–550) | 10.4 ± 2.1 (8.1–14.3) | 0.8 ± 0.1 (0.6–0.9) |
| Ryu et al. [36] | 1   | 25,010                | 15,510.4          | 7370      | 1728      | 364        | NR          | NR                |
| Beavis et al. [37] | 1   | 261,177               | NR                | 2575      | 551       | NR         | NR          | NR                |
| Brogan et al. [38] | 3   | 14,493                | NR                | NR        | NR        | NR         | NR          | NR                |
| Gould et al. [39] | 1   | 53,000                | NR                | NR        | NR        | NR         | NR          | NR                |
| Jeong et al. [40] | 1   | 16,370                | NR                | 1116 ± 33.9 (1092–1140) | 276 ± 8.5 (270–282) | NR         | 0.7 ± 0.2 (0.5–0.8) | NR (1) |
| Kim et al. [41] | 13  | 14,035 (1) >15,000 (12) | 4236 ± 2541.4 (1459–9381) | 1158.9 ± 627.4 (249–2080) | 365.1 ± 187.9 (64–656) | 14.6 ± 14.3 (7.2–61.4) | 1.4 ± 2.1 (0.51–7.39) |
| Ramme et al. [42] | 3   | 95,949.3 ± 49,769.6 (59,651–152,684) | 1075 (1)         | NR        | 662       | 121        | NR          | 0.7 ± 0.2 (0.6–0.9) |
| Hamilton et al. [43] | 1   | 18,200                | NR                | NR        | NR        | NR         | NR          | 0.9                |
| Shim et al. [44] | 23  | >15,000 (23) >1000 (23) | NR | 869 (632.5–1250.5) | 298 (154–378) | 10.6 (8–12.2) | 0.6 (0.5–0.6) |
| Longo et al. [45] | 1   | 74,978                | NR                | NR        | NR        | NR         | NR          | NR                |
| Wong et al. [46] | 5   | NR                    | NR                | NR        | NR        | NR         | NR          | NR                |
| Combined values | 97  | 80,627.8 ± 64,774.4 11,154.5 ± 5575.5 5246 ± 10,063 | 1121 ± 636.9 318.2 ± 169.8 | 11.5 ± 7.8 | 0.9 ± 1 |
classes such as spinning were female [54]. The difference in motivational factors for men and women could possibly be the reason for the high preponderance of women participating in spinning classes. Several studies have shown that females are more likely to participate in group exercise such as spinning classes for social reasons, such as meeting friends or building social bonds [55,56]. Since a large proportion of participants in spinning classes were young adult females, most patients diagnosed with SIER had a similar demographic profile.

Third, we found that most patients who develop SIER are participating in their first spinning session. This is not surprising, as several studies have shown that ER tends to affect individuals who are untrained or unaccustomed to the causative activity [58]. However, there are several factors associated with spinning classes that may predispose individuals to developing ER. Spinning classes are usually high-intensity and are conducted in an indoor group setting with rhythmic musical accompaniment. The Köhler effect is a well-documented phenomenon that describes increased motivational gain in individuals when they perform a task in a group setting [59]. The Köhler effect has been demonstrated in several studies involving different physical activities, such as in participants undergoing stationary bike exercise. Irwin et al. demonstrated that participants who cycled with a more capable partner had significantly increased motivation gain and better performance compared to participants who cycled alone [60]. Thus, spinning in a group setting may spur weaker participants to be more motivated and exert more effort, thereby increasing the risk of developing SIER. In addition, dissociative attention stimuli such as music have also been shown to reduce perceived exertion during strenuous physical activity. A clinical trial showed that listening to music resulted in lower perceived exertion in adults who completed high-intensity exercise on a cycling ergometer [61]. A recent meta-analysis also found that listening to music during physical activity led to reduced perceived exertion. This effect of reduced perceived exertion was further enhanced when music was played at a high tempo [62]. It is therefore highly plausible that a combination of the Köhler effect with high tempo music accompaniment, may lead to increased motivational gain and reduced perceived exertion in spinning class participants, putting them at increased risk of developing SIER.

The classical triad of symptoms associated with ER is myalgia, weakness and dark urine [63]. However, in our study, few patients exhibited this classic triad of symptoms [64]. We found that 69.1% of patients diagnosed with SIER had reported presenting symptoms of myalgia, whilst 56.7% reported dark urine and only 16.5% reported weakness. More importantly, we also found that patients with SIER typically present in a delayed fashion, with a mean time to presentation to a medical facility of 3.1 ± 1.5 days, although symptoms appear much earlier. Healthcare professionals should be cognizant of the variability of symptoms and the potential for delayed presentation in patients with SIER. When in doubt, patients with a suspicious clinical history or symptoms should be referred to the emergency department for diagnostic workup [64]. The absence of dark-colored urine or myoglobinuria also does not preclude the diagnosis of ER, or more specifically, SIER [65].

| Table 3. Sequelae and length of stay. |
|--------------------------------------|
| Author, et al. [26] | N | Acute kidney injury | Temporary hemodialysis | Compartment syndrome | Fasciotomy | Length of stay (days) |
| Bertoldo et al. [26] | 1 | 1/1 | 0/1 | 0/1 | 0/1 | 1/1 | 16 |
| Young et al. [27] | 1 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 | 4 |
| Montero et al. [28] | 9 | 1/9 | 0/9 | 0/9 | 0/9 | 2.1 (1–3)* |
| Boni et al. [29] | 1 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 | 7 |
| Benish et al. [30] | 1 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 | 6 |
| Parmar et al. [31] | 2 | 0/2 | 0/2 | 0/2 | 0/2 | 4 |
| DeFilipps et al. [32] | 2 | 1/2 | 0/2 | 1/2 | 0/2 | 6.5 ± 2.1 (5–8) |
| Cutler et al. [10] | 14 | 1/14 | 0/14 | 1/14 | 1/14 | 4 (1–7) |
| Eichner et al. [33] | 1 | 0/1 | 0/1 | 0/1 | 0/1 | NR |
| Fidan et al. [34] | 1 | 0/1 | 0/1 | 0/1 | 0/1 | 3 |
| Kim et al. [35] | 11 | 0/11 | 0/11 | 0/11 | 0/11 | 7.6 ± 1.9 (6–12) |
| Ryu et al. [36] | 1 | 0/1 | 0/1 | 0/1 | 0/1 | NR |
| Beavis et al. [37] | 1 | 0/1 | 0/1 | 0/1 | 0/1 | 4 |
| Bogran et al. [38] | 3 | 1/3 | 1/3 | 1/3 | 1/3 | NR |
| Gould et al. [39] | 1 | 0/1 | 0/1 | 0/1 | 0/1 | 14 |
| Jeong et al. [40] | 1 | 0/1 | 0/1 | 0/1 | 0/1 | 7.5 ± 2.2 |
| Kim et al. [41] | 13 | 2/13 | 1/13 | 0/13 | 0/13 | 6 (4.5–7) |
| Ramme et al. [12] | 3 | 0/3 | 0/3 | 0/3 | 0/3 | NR |
| Hamilton et al. [42] | 1 | 0/1 | 0/1 | 0/1 | 0/1 | 4 |
| Shim et al. [43] | 23 | 0/23 | 0/23 | 0/23 | 0/23 | 4 |
| Longo et al. [11] | 1 | 0/1 | 0/1 | 0/1 | 0/1 | NR |
| Mong et al. [44] | 5 | 0/5 | 0/5 | 0/5 | 0/5 | 2.4 ± 1.5 (1–4) |
| Combined values | 97 | 7/97 (7.2%) | 2/97 (2.1%) | 4/97 (4.1%) | 4/97 (4.1%) | 5.6 ± 2.9 |

NR not reported

*Data represented as mean (range).

1Continuous individual patient data is summarized to mean ± standard deviation with minimum and maximum values in parentheses, where applicable.

2Data reported as median (range) or median (interquartile range) but converted to mean ± standard deviation (not shown) for pooling using a validated statistical method.
In 97.7% of patients, the signs and symptoms reported during the clinical presentation were predominantly in the thigh. This predominance can be attributed to the muscle groups involved in indoor cycling. In general, the pedal stroke in cycling can be divided into the downstroke and the upstroke. In the downstroke, the quadriceps, hamstrings, and gluteus maximus work together to generate the force required to push the pedal downward [66]. However, one study found that the use of the gluteus maximus was significantly less in indoor cycling than in outdoor cycling, possibly due to the steeper angle of the seat tube [67]. The preferential activation and use of the thigh muscles during spinning classes could therefore be the reason for the high proportion of patients who have symptoms related to the thighs.

The diagnosis of ER is usually based on clinical history and supported by biochemical tests. There must be an antecedent or precipitating exercise activity followed by the onset of muscle-related symptoms. As for biochemical investigations, the diagnosis of ER is typically based on serum CK levels. Serum CK is a reliable diagnostic marker of ER as it gradually rises to its peak 24–36 hours after the initiating exercise activity and then slowly declines back to baseline over the next few days [68]. However, there is no consensus on the diagnostic cutoff value of the serum level CK for ER. Some authors have suggested a value of more than five times the upper limit, while others have suggested a value of more than fifty times the upper limit [69–71]. In our systematic review, we found that most studies had performed and reported CK levels on presentation. In contrast, serum myoglobin levels were only reported in five studies. This paucity of serum myoglobin data likely reflects real-world clinical practice, in which myoglobin is not routinely performed for the diagnosis of ER. Serum myoglobin is rapidly broken down in the liver before being excreted by the kidneys and therefore has a short half-life of only two to three hours. Therefore, serum myoglobin may not be an effective diagnostic marker for rhabdomyolysis, as it may have normalized in most patients at clinical presentation. Serum myoglobin, however, has been shown to have some predictive value in the development of acute kidney injury. In a retrospective study by Premru et al., it was reported that elevated serum myoglobin was correlated with the development of acute kidney injury and the need for renal replacement therapy [72]. In another study by Chen et al., the diagnostic accuracy of initial serum myoglobin for predicting the development of acute kidney injury in patients with rhabdomyolysis was good with an area under curve value of 0.72 [73]. In our systematic review, we also found that liver enzymes were commonly performed and reported. Abnormal liver enzymes are frequently observed in patients with severe rhabdomyolysis and appear to play a predictive role in mortality in critically ill patients with rhabdomyolysis [74]. However, specifically for ER and SIER, the role of abnormal liver enzymes is not well established.

The main goal of management for patients with ER is to prevent complications such as acute renal failure. In our systematic review, all patients received intravenous hydration, which is the main supportive treatment of ER. Patients with ER may be severely hypovolemic due to water sequestration by the injured muscle and must be rehydrated aggressively [75]. Severe hypovolemia and dehydration may lead to electrolyte abnormalities and further increase in CK. Patients who present with SIER usually do not have any comorbidities and should undergo aggressive fluid resuscitation to achieve a urine output of 200–300 ml/hour [17]. However, patients with comorbidities such as congestive heart failure or chronic kidney disease may require a more prudent approach to fluid resuscitation, and early referral to a cardiologist or nephrologist for multidisciplinary management is recommended. In addition to intravenous hydration, one-third of patients with SIER received intravenous sodium bicarbonate. The administration of sodium bicarbonate for alkalization of the urine is routinely performed. For instance, some authors propose a fluid regimen consisting of half isotonic saline and sodium bicarbonate [76]. Alkalization of urine with sodium bicarbonate may reduce precipitation of Tamm-Horsfall protein complexes and the formation of brown granular casts [77]. In addition, urine alkalization has been shown to help decrease redox cycling and lipid peroxidation, preventing oxidative stress, tubular damage, renal vasoconstriction, and potential renal injury [78]. However, there is limited high-quality evidence that alkaline diuresis has a proven clinical benefit over standard saline resuscitation [79,80]. Further studies are therefore needed to determine whether bicarbonate therapy should be part of the standard treatment for SIER.

While we did not observe any long-term sequelae of SIER, a small proportion of patients developed acute kidney injury [10,26,28,32,38,41]. Although two out of the seven patients who developed acute kidney injury required temporary inpatient hemodialysis, no patients developed long-term renal sequelae [38,41]. This finding is consistent with current literature, where a favorable renal prognosis is generally observed following acute kidney injury related to exertional rhabdomyolysis. Several studies have reported the risk of renal failure in healthy young individuals with ER to be from 0% to 8% [81,82]. In our systematic review, aside from transient renal dysfunction, four patients with SIER developed compartment syndrome of the thigh requiring fasciotomies. Compartment syndrome in the setting of ER is a rare complication and develops initially due to severe muscle edema. Severe muscle edema can impede venous return and lead to a vicious cycle of worsening muscle edema and rising compartmental pressures. Eventually, arterial inflow can be compromised due to high compartment pressure, which can lead to muscle ischemia and death, and further CK and myoglobin release [83]. We must have a high index of suspicion for compartment syndrome if the pain does not improve or subside with medical management [84]. As the clinical diagnosis of compartment syndrome in patients with SIER can be challenging due to overlapping signs and symptoms; we should consider using a handheld pressure monitor to evaluate the compartmental pressures of the lower extremities if compartment syndrome is suspected [85]. A compartmental pressure of more than 30 mmHg is suggestive of compartment syndrome [86]. Expedient diagnosis and treatment are vital to prevent sequelae such as irreversible muscle damage, nerve injury or limb ischemia.
With the increasing popularity of spinning, there is an urgent need to exercise greater caution to prevent SIER. Guidelines should be established for the public recommending safe entry into indoor spinning. First and foremost, participants of spinning classes, especially first-timers, should be adequately educated on risk reduction strategies for SIER such as adequate hydration and rest before the activity. Second, spinning classes should be conducted in a cooling, well-ventilated environment to reduce the risk of heat injury or heat-induced rhabdomyolysis. Third, participants in spinning classes should be subjected to a mandatory screening questionnaire to identify specific risk factors associated with ER. Fourth, spinning classes should take precautions by reducing the intensity of exercise for novice spinners by prescribing a graded program. Fifth, spinning instructors should be taught how to identify participants at higher risk of developing SIER. Next, there should be greater public awareness of the signs and symptoms of SIER such that patients can seek medical attention earlier. Finally, medical professionals should know the clinical signs and symptoms of SIER and have a high index of suspicion to diagnose SIER. Early intervention is crucial to prevent short- and long-term consequences of SIER.

The results of this review should be interpreted in the context of known limitations. First, due to the methodology and small sample size of the studies included in this systematic review, we were unable to conduct a formal weighted statistical analysis. Therefore, we were unable to establish or identify a causal relationship between indoor spinning and the development of ER. Second, due to the sparse information in the included articles, we are unable to fully determine the impact of confounding factors that may contribute to the development of ER, such as patient comorbidities, hydration status or even environmental factors during the spinning session. Third, the majority of the articles included in our systematic review were case reports or case series, which may be associated with substantial publication bias, where only positive or interesting results are published. Finally, most of the included studies only reported outcomes up to discharge and not long-term follow-up data. It would be interesting to know if the development of SIER could lead to any late effects.

5. Conclusions

In conclusion, our article provides a comprehensive overview of the demographics, patient characteristics, and outcomes of SIER. SIER is a condition that the medical community will face with increasing frequency due to the popularity of spinning classes. As medical professionals, we need to be aware of the risk factors and clinical presentation of SIER. To mitigate the risk of developing SIER, formal guidelines for participation in spinning classes should be developed.

Disclosure statement

No potential conflict of interest was reported by the author(s).
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