The effect of extracorporeal shock wave on osteonecrosis of femoral head: a systematic review and meta–analysis

Jin Mei, Lili Pang and Zhongchao Jiang
Hospital of Chengdu University of Traditional Chinese Medicine, Chengdu, China

ABSTRACT

Introduction: This study aims to determine whether ESWT (extracorporeal shock wave therapy) affects ONFH (ostearthritis of femoral head) in clinical outcomes and radiography outcomes.

Method: Two authors independently search the papers on the treatment of femoral head necrosis with extracorporeal shock wave in CNKI (China National Knowledge Infrastructure), VIP (China Science and Technology Journal Database), CSPD (China Science Periodical Database), Pubmed, Embase, and Springer databases. Search period from the inception dates to 2 June 2020 and have no limitations in language; two authors independently conducted a quality evaluation and data extraction for included studies and performed a meta-analysis with data extracted and calculate by using RevMan5. Registration number: CRD42020213580.

Result: Nine articles with 409 patients are included in this meta-analysis. The pooled results of HHS (Harris hip score) in eight studies with 337 hips show that ESWT achieves higher Harris scores compared to before treatment (MD = −19.95; 95% CI: −26.27, −13.64) and the difference is statistically significant (p < 0.01). The pooled results of VAS (visual analogue score) in seven studies with 253 hips show that ESWT achieves lower VAS compared to baseline (MD = 2.77; 95% CI: 1.88, 3.65) and the difference is statistically significant (p < 0.01). The pooled results of lesion of MRI with 164 hips show that ESWT decreases the lesion area of MRI (SMD = 1.03; CI: 0.75,1.30) and the difference is statistically significant (p < 0.01).

Conclusion: ESWT has an effect on pain relief and has a limited effect on motion function. Its effect may be better than surgical groups (core decompression and core decompression with bone grafting). But it cannot decrease the lesion area of the femoral head on MRI and stop disease progression.

Introduction

Osteonecrosis of femoral head is also known as avascular necrosis of the femoral head (AVNFH) or aseptic necrosis of the femoral head (ANFH) [1]. About 20,000 to 30,000 new patients are diagnosed with ONFH per year in the United States [2]. Approximately 2200 additional patients would diagnose with ONFH annually in Japan [3]. The pain of the patient in the deep groin is the most common symptom and may influence the knee or ipsilateral buttock [4]. Degenerative changes of the hip and the collapse of the femoral head occur later in the disease. Young adults in the pre-collapse stage need to keep the femoral head intact considering the limited lifespan of a prosthesis. Therefore, early intervention is important and ESWT may be an important treatment approach. Current treatment of hip preservation include core decompression combined with other therapies or core decompression alone, nonvascularized or vascularized bone-grafting, and rotational osteotomy [5–7]. These methods have different effects and only treat patients with early necrosis of femoral head. Therefore, a noninvasive alternative to surgery is important.

Extracorporeal shock wave therapy is a noninvasive treatment that applies in varied diseases. In addition, it is also implemented in orthopedics and traumatology for a period with a boom [8]. Nowadays, the application of ESWT in musculoskeletal disorders mainly included tendinopathies and bone defects [9]. In an animal experiment, ESWT may promote bone repair and increase bone mass in the necrotic femoral head [10]. In the first article about ESWT to ONFH published in 2001, Thiel M proposed that ESWT provide a suitable noninvasive way to treat ONFH [8]. Many articles show ESWT has an improvement in patients using the evaluation of HHS and VAS [11–13]. A case report even proved the efficiency of ESWT in patients with a stage of ARCO (Association Research Circulation Osseous) IV, but more random control trial needs to prove it is efficacious in advanced disease [14].

To evaluate ESWT’s effect on ONFH and its long-term efficacy, we identify all suitable clinical trials from the electronic database and conduct this meta-analysis thoroughly to probe...
the influence of ESWT in HHS and VAS and the changes of lesion area of the femoral head on MRI.

Methods

Study selection

We select Studies using PubMed, Embase, the Cochrane Library, CSPD, VIP, and CNKI databases from the inception dates to 24 October 2019, by two authors, without language restriction. We use ‘ESWT,’ ‘Extracorporeal shock wave,’ ‘Extracorporeal shockwave,’ ‘osteonecrosis,’ ‘Osteonecrosis of the Femoral Head,’ ‘avascular necrosis of bone,’ ‘aseptic necrosis of the femoral head,’ ‘ONFH’ and ‘necrosis of the femoral head’ as the keywords. According to different database retrieval formats, the keywords combine with free words and Medical Subject Headings (MeSH) terms in the database for full-text searched, and the reference documents of the search literature are tracked.

Inclusion criteria

Studies were included in this meta-analysis met the following criteria: (1) Studies using extracorporeal shock waves as an intervention with a control group; (2) studies object: a clear diagnosis of femoral head necrosis in radiology image or MRI and there is no limited to gender, age, course of the disease, and etiology; (3) Outcome indicator: main outcome indicators are HHS and VAS; secondary outcome indicator is the progress of MRI.

Exclusion criteria

Exclusion criteria are followed as below: (1) Review, case report, meetings abstracts, animal studies, editorial letters, guidance or comments; (2) No clear diagnostic criteria for disease; (3) Repeated studies; (4) incomplete data or data cannot be compared even after a calculation; (5) duration of follow-up less than six months; (6) sample size are less than 10 patients.

Quality assessment

We use the National Institute for Clinical Excellence (NICE) case series scoring standard to evaluate the case series study, and the case-control study is evaluated by the Newcastle-Ottawa Scale (NOS). We grade the random control trial (RCT) according to the modified jaded score. Four items are evaluated including the adequacy of the randomization process (2 points), the adequacy of allocation concealment (2 points), double-blinding (2 points), and withdrawals and dropouts (2 points). Two researchers independently conduct a rigorous quality evaluation of the included literature by using the above scoring scale. When different views occur, the discussion is conducted with all researchers to solve the issue.

Data extraction

Two researchers independently extract the following information from each study: first author, year of publication, participant characteristics, study design, follow-up duration, the total number of ONFH patients and hips, the average age of patients, the pulses and energy flux density of ESWT, classification of disease, and the risk factor. The clinical outcomes of our study include The HHS of patients before ESWT and after ESWT, the visual analogue scale pain score of patients before and after ESWT, rate of conversion to THA, and the degree of radiographic progression.

Statistical analysis

We conduct this meta-analysis using RevMan5 (Chengdu, China). Considering HHS, VAS, and progress of imaging are all expressed by quantitative data, we use mean difference (MD) to analyze continuous outcomes with 95% confidence intervals (CI). When parameters are measured in different ways or have a different unit of measurement, we use the standard mean difference (SMD) to analyze continuous outcomes. Chi-squared tests and the I² statistic are used to evaluate statistical heterogeneity. An I² > 50% is considered that compared studies have significant statistical heterogeneity and a subgroup analysis is carried out to find the cause of heterogeneity and then decide to use random-effect or fixed-effect model. We perform an egger test to evaluate publication bias. Values of P < 0.05 is considered statistically significant. If the heterogeneity cannot be eliminated by subgroup analysis, a sensitivity analysis will be performed. We evaluate the publication bias with an egger test by using STATA 15.

Result

Literature search

The process of the literature search is illustrated in Figure 1, a total of 604 potentially relevant articles are identified from 6 databases. Three hundred and eleven duplicated articles are excluded by using Endnotes. After a title and abstract are screened, 274 articles are excluded. Forty-six records are considered potentially eligible and full-text review, but 37 are excluded for different reasons (27 articles lack crucial data, six articles follow-up less than 6 months, and 4 articles sample sizes less than 10 cases). Finally, nine articles are reflected in the present meta-analysis [15–23].

Study characteristics

The basic characteristics of the included studies are shown in Table 1. A total of 409 patients are from the 9 articles. Their information is as follows: an average age of approximately 43.24 (18–69) years, a pulse range from 800 to 6000, a female ratio of approximately 29.83%, and an energy flux density range from 0.12 to 0.51 ml/mm² with an average follow-up of 54.3 (6–228) months. Nine studies included one RCT, three case-control studies, and five case series studies. The RCT study is assessed according to the modified jaded scale and received 4 points. Five case series are applied in the NICE case series scoring criteria for quality evaluation and ranked an average point of 5.4. We use NOS scales to evaluate three case controls and received an average score of 8.2.
Figure 1. Flow chart of study selection, using PRISMA (Preferred Reporting Items for Systematic Meta-Analyses) guidelines.

Table 1. Basic characteristics of included studies.

| Included trials | Year  | Study style | Number/hips | Women, no(%) | Mean age (y) | Treatment        | Pulses | Energy flux density | Follow-up(months) |
|-----------------|-------|-------------|-------------|--------------|--------------|-------------------|--------|---------------------|-------------------|
| Xing            | 2003  | case series | 69/NA       | 17 (25%)     | 41.9 (19-56) | ESWT              | 1000   | 0.18 ~ 0.25 mJ/mm²  | 12                |
| Wang et al      | 2012  | case control| 25/28       | 5 (10%)      | 39.8 ± 12.1 (19-63) | ESWT CD+BG | 6000   | 0.474 mJ/mm²        | 103.5 ± 3.4 (93-106) |
|                 |       |             | 25/28       |              | 39.9 ± 9.3 (19-55)      |                |   /                | 104.5 ± 4.3 (95-108) |
| Cheng           | 2015  | case series | 26/30       | 10 (38%)     | 43.1          | ESWT              | 1000   | 0.18 ~ 0.25 mJ/mm²  | 12                |
| Han et al       | 2016  | case control| NA/15       | 6 (32%)      | 64.9±6.4     | ESWT              | 1000   | 0.12 mJ/mm²         | 6                 |
|                 |       |             | NA/15       |              | 63.8±6.2     | ESWT              | 1000   | 0.22 mJ/mm²         | 6                 |
| SU              | 2016  | case series | 30/38       | 11 (37%)     | 42.3 (23-68) | ESWT              | 1000   | 0.20 ~ 0.35 mJ/mm²  | 16.3 (12-24)      |
| Wang et al      | 2016  | RCT         | 10/16       | 6 (30%)      | 46.1±6.2 (35-55) | ESWT              | 2000   | 0.510 mJ/mm²        | 33.8±7.6 (18-45)  |
|                 |       |             | 11/14       |              | 40.5±9.3 (29-60) | ESWT              | 4000   | 0.510 mJ/mm²        | 30.0±7.1 (18-44)  |
|                 |       |             | 12/12       |              | 39.4±10.2 (18-52) | ESWT              | 6000   | 0.510 mJ/mm²        | 30.7±8.0 (18-45)  |
| WU              | 2017  | case control| 69/79       | 22 (32%)     | 43.5 ± 12.7 (18-67) | ESWT CD | 800    | NA                  | 96 (80-113)       |
|                 |       |             | 63/82       | 21 (33%)     | 44.8 ± 14.1 (18-69) |                |   /                |                    |
| Algarini et al  | 2018  | case series | 21/33       | 12 (57%)     | 37.5 ± 4.8 (21-54) | ESWT              | 1500   | NA                  | 60 ± 42 (24-108)  |
| Xie             | 2018  | case series | 31/44       | 8 (26%)      | 41.2±22.0 (20-60) | ESWT              | 1000   | NA                  | 130.6±121-133     |

RCT: random control trial. ESWT: extracorporeal shock wave therapy. CD: core decompression. CD+BG: core decompression + bone grafting. NA: not available.
The HHS of patients before and after ESWT

Harris hip score scored patients according to four parts including pain, function, deformity, and range of motion. The more score patients get, the better function patients have. A score of less than 70 is poor, 70–80 is fair, 80–90 is good, and 90–100 excellent. The pooled results of HHS with eight studies of 337 hips show that ESWT achieves a higher Harris hip score after treatment (MD = −20.03; 95% CI: 25.56, −14.49; Figure 2) and the difference is statistically significant (p < 0.01). However, the heterogeneity analysis shows an excessive heterogeneity (I² = 91%). According to the language of articles, we divide articles into the Chinese group and the English group and perform a subgroup analysis (Figure 3). In subgroup analysis, the heterogeneity of the English group is eliminated. Extracorporeal shock wave therapy also achieves higher scores compared to baseline scores.

The VAS of patients before and after ESWT

The visual analogue score is the level of pain expressed by eleven figures from 0 to 10. 0 means no pain and 10 means excessive pain. Patients chose one figure to express their degree of pain. The pooled results of VAS with seven studies of 253 hips demonstrate that ESWT group achieve lower VAS scores after treatment (MD = 2.77; 95% CI: 1.88, 3.65; Figure 4) and the difference is statistically significant (p < 0.01). However, the heterogeneity analysis shows an excessive heterogeneity (I² = 86%). So, we perform subgroup analysis (Figure 5). Studies are divided into the low score group and the high score group according to the degree of the pain score decreased. In subgroup analysis, the heterogeneity of the low score group is eliminated. All groups of ESWT achieve lower scores compared to baseline scores and the difference is statistically significant (p < 0.01).

Changes of lesion area on MRI before and after ESWT

Six studies are included in this meta-analysis. We select SMD as consolidated statistics due to different concepts of lesions in the 4 articles. The pooled results of lesion of MRI with 164 hips show that ESWT decreases the lesion area of MRI after treatment (SMD = 1.03, CI: 0.75, 1.30, Figure 6) and the difference is statistically significant.
However, only two of them are statistically significant. The heterogeneity analysis also shows excessive heterogeneity ($I^2 = 97\%$).

**Effect of ESWT compare to surgical therapy in HHS and VAS**

Two studies compared ESWT to the surgical method (core decompression or core decompression with bone grafting) in HHS and VAS [16,21]. We use degree of changed score as effect size to evaluate the effect of different intervention methods and conduct a calculation to get compared data by using raw data. The polled result of two studies of 180 patients (218 hips) show that ESWT has a better improvement in HHS (MD = 13.64; 95% CI, 10.60,16.65; Figure 7) compared to surgical therapy, the difference is statistically significant ($p < 0.01$). Extracorporeal shock wave therapy also have a better effect on pain relief compared to surgical method (SMD = 1.25; 95% CI, 0.95,1.54; Figure 7).
Etiologic factors
A total of 5 studies (170 patients) record the etiologic factors and the number of patients. Alcohol is the most common etiologic factor (66 patients, 39%), followed by corticosteroid (43 patients, 25%) and idiopathic (42 patients, 25%).

Change of ARCO stage before and after ESWT
Association Research Circulation Osseous staging is more systematic, more comprehensive, and more practical compared to the staging of ONFH. Two articles record the ARCO stage of patients before and after ESWT. It is shown in Figure 8. Considering 3 patients are lost to follow-up, there is no significant change in the ARCO stage before and after ESWT (p > 0.05).

Rate of total hip arthroplasty
Three articles (104hips) record the rate to THA (total hip arthroplasty). Four hips were converted to THA at an average of 3.7 years after ESWT in Alqarni AD study (range, 2–8 years) [22]. Four of 42 hips underwent THA at an average of 31.4 ± 7.5 months in Wang CJ study [18]. The duration of follow-up reach 8–9 years in one study with a rate of THA was 24% (7 of 29 hips). However, the hip arthroplasty rate of the surgical group (core decompression) reaches 64% (18 of 28 hips) [16]. In the total number of 104 hips, about 19.2% hips develop to a THA, and 80.8% of hips are survived.

Sensitive analysis
In the comparison of the visual analogue score before and after ESWT, and the heterogeneity (I² = 54%) still exists in the high score group after a subgroup analysis (Figure 5). So a sensitivity analysis is performed. When the study of Wu 2017 is omitted, the heterogeneity (I² = 24%) is significantly reduced. So we read this article again to find the reason. The relatively small number of pulses may be one reason for this heterogeneity. This article type is case-control and the lack of a blinding method may be another reason.

Publication bias
We perform an egger test to evaluate the publication bias of the change of HHS sore (Figure 9). It can be referred that there is no publication bias by the p-value. The value of p is 0.477 and more than 0.05.

Discussion
In this meta-analysis, 9 studies with 409 patients are included. We evaluate the effect of ESWT on pain relief and motion function by comparing the change of the HHS and the VAS. The lesion area on MRI before and after ESWT are compared and we also perform a comparison on ESWT and surgical
therapy (core decompression or core decompression with bone grafting).

Patient HHS is considerably improved after ESWT. Following consideration of the heterogeneity, we perform a subgroup analysis to eliminate the heterogeneity. This subgroup analysis shows the difference between Chinese articles and English articles, it may be caused by race. But no matter what the reason is, the HHS of each group of patients is enhanced to different degrees after ESWT. A score of less than 70 is poor, 70–80 is fair, 80–90 is good, and 90–100 excellent. Although the score improved after extracorporeal shock wave therapy, the patient still ranked low scores (<70) in Han's articles. Extracorporeal shock wave therapy also shows powerful ability in decreasing visual analogue score. But there are also exist the heterogeneity. It may be influenced by the measurer's induction and personal subjective feelings. So we perform subgroup analysis according to the degree of the score decreased. Heterogeneity ($I^2 = 54\%$) still exists in the high score group after a subgroup analysis. So a sensitivity analysis was performed. When the study of Wu 2017 is omitted, the heterogeneity ($I^2 = 24\%$) is significantly reduced. The relatively small number of pulses and the type of this article may cause it. This outcome shows ESWT can reduce pain and improve motor function and range of motion. Compared to core decompression or core decompression with bone grafting, extracorporeal shock wave therapy also have an advantage in pain relief and improvement in motor function.

One article shows that ESWT may halt or delay the radiographic progression of the disease in the precollapse stage. However, confidence intervals of four studies included 0, it can be referred that ESWT has no obvious effect on changing the lesion area of ONFH. There are no significant improvements in the lesion area of the femoral head on MRI in our meta-analysis and no significant change in the ARCO stage before and after ESWT.

Compared to core decompression or core decompression with bone grafting, extracorporeal shock wave therapy has an advantage in pain relief and improvement in motor function in this meta-analysis. Italian experience on the use of ESWT for ONFH also shows it is an efficient method in the initial stages of the disease and better than core decompression and bone grafting [24]. A combination treatment of alendronate, extracorporeal shock, and hyperbaric oxygen is effective for early hip necrosis comparable to ESWT in short-term follow-up. Further studies are necessary to prove the long-term effect of this combination treatment.

For the above etiologic factor of ONFH, complications of treating leukemia also included ONFH. Extracorporeal shock wave also shows an efficient effect on ONFH causing by leukemia in the short term by resolving the suffering of bone marrow edema [26].

The stage of ONFH may be an important factor for the rate to THA. Vulpiani et al. found that 66% of ARCO III hips develop to THA at final follow-up [27]. Extracorporeal shock wave group had a lower rate to THA compared to the surgical group. Even in a long-term follow-up, extracorporeal shock wave therapy group also shows a low rate to THA. Besides, one article shows a low degree of ARCO had a lower rate to THA [19]. So ESWT may decrease the rate of THA in an early stage of ONFH.

Extracorporeal shock wave therapy is reported to treat a variety of disorders effectively [28], such as diabetic feet, Erectile Dysfunction, Plantar Fasciitis, and ONFH, especially for ONFH [29–32]. The mechanism of ESWT in the treatment of femoral head necrosis is not completely clear [33]. One hypothesis is that ESWT could induce microfracture to accelerate bone healing and increase pain threshold [13]. L. Z. et al. proposed that moderate extracorporeal shock wave intensity can enhance MSCs (mesenchymal stem cells) proliferation, inducing the development of MSCs into osteoblasts, and prevented MSCs from converting adipocytes. This might be a mechanism that ESWT can treat ONFH [34]. Extracorporeal shock wave therapy enhances angiogenic and osteogenic effects of the MSCs utilizing the nitric oxide pathway [35]. Ma et al. believed that ESWT may increase blood supply and repair necrotic subchondral bone by reinforcing the expression of vascular endothelial growth factor [36]. More basic experiments on the mechanism of ESWT need to be carried out.

**Limitation**

Limitations exist in this meta-analysis. First, one study only has 6 months follow up [17]. Second, only one RCT has included this meta-analysis, the quality of the included studies is poor accompanied by a low level of evidence. In addition, the variance of populations, VAS, and the way of ESWT contributed to a high level of heterogeneity. Therefore, more rigorous
RCT is needed to identify the effect of ESWT compared to other treatment methods.

Conclusion
This meta-analysis suggests that ESWT improves motion function, range of motion, and relieves pain in the early stages of the disease. Extracorporeal shock wave therapy has a lower rate to THA compared to the surgical group (core decompose or core decompression with bone grafting), but there is no significant change in the lesion area of the femoral head on MRI and stage change after ESWT.

Acknowledgments
Not applicable

Declaration of interest
The authors declare that they have no conflict of interests.

Availability of data and materials
Data sharing is not applicable to the current study.

Consent for publication
Written informed consent for publication is obtained from all participants.

Ethics approval and consent to participate
This article does not contain any studies with human participants or animals performed by any of the authors.

Funding
This research does not receive any funding.

Declaration of interest
No.

References
1. Chineese guideline for the diagnosis and treatment of osteonecrosis of the femoral head in adults. Orthop Surg. 2017 Feb 9(1):3-12.
2. Moya-Angeler J, Gianakos AL, Villa JC, et al. Current concepts on osteonecrosis of the femoral head. J World J orthopedics. 2015;6 (8):590-601.
3. Kubo T, Ueshima K, Saito M, et al. Clinical and basic research on steroid-induced osteonecrosis of the femoral head in Japan. J orthopaedic sci. 2016;21(4):407-413.
4. Zalavras CG, Lieberman JR. Osteonecrosis of the femoral head: evaluation and treatment. J Am Acad Orthop Surg. 2014 Jul;22 (7):455–464.
5. Koo KH, Kim R, Ko GH, et al. Preventing collapse in early osteonecrosis of the femoral head. A randomised clinical trial of core decompression. J Bone Joint Surg Br. 1995;77-B(6):870–874.
6. Learmonth ID, Maloon S, Dall G. Core decompression for early atraumatic osteonecrosis of the femoral head. J Bone Joint Surg Br. 1996;72(3):387–390.
7. Saito S, Ohzono K, Ono K. Joint-preserving operations for idiopathic avascular necrosis of the femoral head. Results of core decompression, grafting and osteotomy. J Bone Joint Surg Br. 2015;6(1):78-84.
8. Thiel M, Nieswand M, Dörfel M. Review: the use of shock waves in medicine—a tool of the modern OR: an overview of basic physical principles, history and research. Minimally Invasive Therapy Allied Technologies. 2000;9(4):247–253.
9. Saggini R, Di Stefano A, Saggini A, et al. Clinical application of shock wave therapy in musculoskeletal disorders: part I[J]. J Biol Regul Homeost Agents. 2015;29:533–545.
10. Ma H-Z, Zhou D-S, Li D, et al. A histomorphometric study of necrotic femoral head in rabbits treated with extracorporeal shock waves. J Phys Ther Sci. 2017 Jan;29(1):24–28.
11. Ludwig J, Lauber S, Lauber H-J, et al. High-energy shock wave treatment of femoral head necrosis in adults. Clinical Orthopaedics and Related Research. 2001;387:119–126.
12. Lee J-Y, Kwon J-W, Park J-S, et al. Osteonecrosis of femoral head treated with extracorporeal shock wave therapy: analysis of short-term clinical outcomes of treatment with radiologic staging. Hip & Pelvis. 2015 Dec;27(4):250–257.
13. Gao F, Sun W, Li Z, et al. High-energy extracorporeal shock wave for early stage osteonecrosis of the femoral head: a single-center case series. Evid Based Complement Alternat Med. 1988:70-B:68090.
14. Ma YW, Jiang DL, Zhang D, et al. Radial extracorporeal shock wave therapy in a patient with advanced osteonecrosis of the femoral head. Am J Phys Med Rehabil. 2016 Sep;95(9):e133–9.
15. Gengyan X, Xiaodong B, Mingkui D, et al. Efficacy of extracorporeal shock wave in the treatment of avascular necrosis of the femoral head in adults J Chin J Phys Med Rehabil. 2003 Aug;25(8):28–130.
16. Wang CJ, Huang CC, Wang JW, et al. Long-term results of extracorporeal shockwave therapy and core decompression in osteonecrosis of the femoral head with eight- to nine-year follow-up. Biomed J. 2012;35:481–485.
17. Cheng Y, Li Ping, Efficacy analysis of ESWT in the treatment of avascular necrosis of the femoral head J China Med Sci. 2015;5:20–26.
18. Wang C-J, Huang C-C, Yip H-K, et al. Dosage effects of extracorporeal shockwave therapy in early hip necrosis. Int J Surg. 2016;35:179–186.
19. Su Y, Yuyu C, Liang Y, et al. Clinical observation of high-energy extracorporeal shock wave in the treatment of early femoral head necrosis J Biotechnol World. 2016; 87–88.
20. Han Y, Lee J-K, Lee B-Y, et al. Correction: effectiveness of lower energy density extracorporeal shock wave therapy in the early stage of avascular necrosis of the femoral head. Annals of Rehabilitation Medicine. 2017;41(2):337–338.
21. Ehrhart IC, P E, P, Weidner W, et al. Coronary vascular and myocardial responses to carotid body stimulation in the dog. The American Journal of physiology. 1975;229(3):48–51.
22. Algarni AD, Al Moalem HM. Clinical and radiological outcomes of extracorporeal shock wave therapy in early-stage femoral head osteonecrosis. Adv Orthop. 2018;74:10246.
23. Xie K, Mao Y, Qu X, et al. High-energy extracorporeal shock wave therapy for nontraumatic osteonecrosis of the femoral head. J Orthop Surg Res. 2018;3(1):25.
24. Russo S, Sadile F, Esposito R, et al. Italian experience on use of E.S. W. therapy for avascular necrosis of femoral head. Int J Surg. 2015 Dec;24( Pt B):188–190.
25. Liu T, Ma J, Su B, et al. A 12-year follow-up study of combined treatment of post-severe acute respiratory syndrome patients with femoral head necrosis. Ther Clin Risk Manag. 2017 Oct 19;13:1449–1454.
26. Te Winkel ML, Pieters R, Wind EJ, et al. Management and treatment of osteonecrosis in children and adolescents with acute lymphoblastic leukemia. Haematologica. 2014 Mar;99(3):430–436.
27. Vulpiani MC, Vetranio M, Trischitta D, et al. Extracorporeal shock wave therapy in early osteonecrosis of the femoral head: prospective clinical study with long-term follow-up. Arch Orthop Trauma Surg. 2012 Apr;132(4):499–508.
28. Crevenna R, Mickel M, Schuhfried O, et al. Focused extracorporeal shockwave therapy in physical medicine and rehabilitation. Curr Phys Med Rehabil Rep. 2021;9:1–10.
29. Yang JP, Lee YN, Son JW, et al. The impact of extracorporeal shock wave therapy on microcirculation in diabetic feet: a pilot study. Adv Skin Wound Care. 2019 Dec;32(12):563–567.
30. Kim KS, Jeong HC, Choi SW, Choi HJ, Ha US, Hong SH, Lee JY, Lee SW, Ahn ST, Moon DG, Bae WJ, Kim SW. Electromagnetic low-intensity extracorporeal shock wave therapy in patients with erectile dysfunction: a sham-controlled, double-blind, randomized prospective study. World J Mens Health. 2020 Apr;38(2):236–242.
31. Xu D, Jiang W, Huang D, et al. Comparison between extracorporeal shock wave therapy and local corticosteroid injection for plantar fasciitis. Foot Ankle Int. 2020 Feb;41(2):200–205.
32. Tang HY, Zhao Y, Li YZ, et al. Effectiveness of extracorporeal shock wave monotherapy for avascular necrosis of femoral head: a systematic review protocol of randomized controlled trial. Medicine (Baltimore). 2019 Apr;98(14):e15119.
33. Cheng JH, Wang CJ. Biological mechanism of shockwave in bone. Int J Surg. 2015 Dec;24(Pt B):143–6.
34. Zhai L, Sun N, Zhang B, et al. Effects of focused extracorporeal shock waves on bone marrow mesenchymal stem cells in patients with avascular necrosis of the femoral head. Ultrasound Med Biol. 2016 Mar;42(3):753–762.
35. Yin TC, Wang CJ, Yang KD, et al. Shockwaves enhance the osteogenetic gene expression in marrow stromal cells from hips with osteonecrosis. Chang Gung Med J. 2011 Jul-Aug;34(4):367–374.
36. Ma HZ, Zeng BF, Li XL. Upregulation of VEGF in subchondral bone of necrotic femoral heads in rabbits with use of extracorporeal shock waves. Calcif Tissue Int. 2007 Aug;81(2):124–131.