

# Management of Posttraumatic Osteoarthritis With an Integrated Orthotic and Rehabilitation Initiative

CPT Jeanne C. Patzkowski, MD,  
MC, USA

Johnny G. Owens, MPT

Ryan V. Blanck, LCPO

Kevin L. Kirk, DO

Joseph R. Hsu, MD

Skeletal Trauma Research  
Consortium

## Abstract

Posttraumatic osteoarthritis affects approximately 5.6 million Americans annually. Those affected are typically younger and more active than persons with primary osteoarthritis. Arthrodesis is the typical management option for persons with end-stage ankle and subtalar posttraumatic arthritis. Arthroplasty is typically reserved for elderly persons. The functional limitations resulting from any of these strategies make treatment of this young population challenging. Combat wounds frequently lead to severe lower extremity injuries. We present a series of patients with severe posttraumatic osteoarthritis of the ankle and subtalar joint after combat trauma. They were treated at our institution with an integrated orthotic and rehabilitation initiative called the Return To Run clinical pathway. This clinical pathway may serve as an alternative or adjunct to arthrodesis and arthroplasty for young patients with severe posttraumatic osteoarthritis of the ankle and subtalar joint.

From the San Antonio Military Medical Center (Dr. Patzkowski and Dr. Kirk), the United States Army Institute of Surgical Research (Dr. Patzkowski and Dr. Hsu), and the Center for the Intrepid, Fort Sam Houston, TX (Mr. Owens and Mr. Blanck).

This study was conducted under a protocol reviewed and approved by the Brooke Army Medical Center Institutional Review Board and in accordance with the approved protocol. The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

*J Am Acad Orthop Surg* 2012;  
20(suppl 1):S48-S53

<http://dx.doi.org/10.5435/JAAOS-20-08-S48>

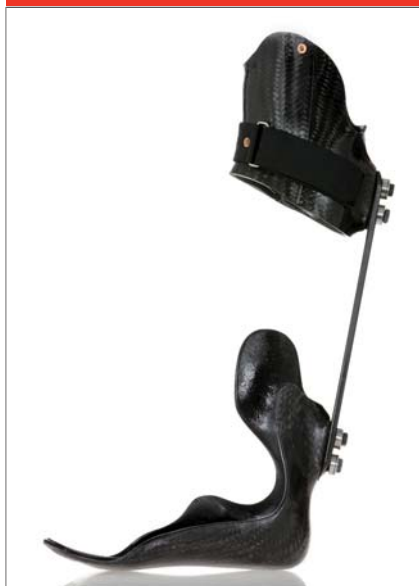
Copyright 2012 by the American Academy of Orthopaedic Surgeons.

Osteoarthritis (OA) is among the most common and most disabling conditions affecting adults in the United States.<sup>1</sup> Posttraumatic osteoarthritis (PTOA), which may arise due to intra-articular fracture or ligamentous or other soft-tissue injury, typically affects younger (<60 years), more active persons than does primary OA.<sup>2-4</sup> Multiple factors are believed to contribute to PTOA. Although the precise role of each factor has not been elucidated, they likely work in concert to cause end-stage joint degeneration.<sup>5-11</sup> Primary OA accounts for a small portion of the total burden of ankle arthritis; in contrast, primary OA accounts for a much higher burden of arthritis in the hip and knee.<sup>12,13</sup> PTOA of the

ankle, however, is relatively frequent; up to 80% of all cases of ankle arthritis are considered to be posttraumatic.<sup>7,14,15</sup> Approximately 12% of adults in the United States, or 5.6 million people, are affected by PTOA, at an annual direct cost of approximately \$3 billion.<sup>14</sup>

In combat-wounded populations, the incidence of musculoskeletal trauma is high, particularly trauma to the lower extremities.<sup>16,17</sup> Several published reports have noted an increase in high-energy explosive wounding mechanisms, which frequently lead to severe neurologic, vascular, and soft-tissue compromise, with extensive contamination and fragmentation injury.<sup>16-19</sup> Chronic pain, nerve injuries, and volumetric

| Report Documentation Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                    |                                     |                                                           | Form Approved<br>OMB No. 0704-0188                  |                                 |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-------------------------------------|-----------------------------------------------------------|-----------------------------------------------------|---------------------------------|
| Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.                                                                                                                                                                                          |                                    |                                     |                                                           |                                                     |                                 |
| 1. REPORT DATE<br><b>AUG 2012</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                    | 2. REPORT TYPE                      |                                                           | 3. DATES COVERED<br><b>00-00-2012 to 00-00-2012</b> |                                 |
| 4. TITLE AND SUBTITLE<br><b>Management of Posttraumatic Osteoarthritis With an Integrated Orthotic and Rehabilitation Initiative</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                    |                                     |                                                           | 5a. CONTRACT NUMBER                                 |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                    |                                     |                                                           | 5b. GRANT NUMBER                                    |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                    |                                     |                                                           | 5c. PROGRAM ELEMENT NUMBER                          |                                 |
| 6. AUTHOR(S)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                    |                                     |                                                           | 5d. PROJECT NUMBER                                  |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                    |                                     |                                                           | 5e. TASK NUMBER                                     |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                    |                                     |                                                           | 5f. WORK UNIT NUMBER                                |                                 |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><b>United States Army Institute of Surgical Research, Fort Sam Houston, TX, 78234</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                    |                                     |                                                           | 8. PERFORMING ORGANIZATION REPORT NUMBER            |                                 |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                    |                                     |                                                           | 10. SPONSOR/MONITOR'S ACRONYM(S)                    |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                    |                                     |                                                           | 11. SPONSOR/MONITOR'S REPORT NUMBER(S)              |                                 |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br><b>Approved for public release; distribution unlimited</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                                           |                                                     |                                 |
| 13. SUPPLEMENTARY NOTES<br><b>Journal of the American Academy of Orthopaedic Surgeons, August 2012 vol. 20 no. suppl S48-S53</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                    |                                     |                                                           |                                                     |                                 |
| 14. ABSTRACT<br><b>Posttraumatic osteoarthritis affects approximately 5.6 million Americans annually. Those affected are typically younger and more active than persons with primary osteoarthritis. Arthrodesis is the typical management option for persons with end-stage ankle and subtalar posttraumatic arthritis. Arthroplasty is typically reserved for elderly persons. The functional limitations resulting from any of these strategies make treatment of this young population challenging. Combat wounds frequently lead to severe lower extremity injuries. We present a series of patients with severe posttraumatic osteoarthritis of the ankle and subtalar joint after combat trauma. They were treated at our institution with an integrated orthotic and rehabilitation initiative called the Return To Run clinical pathway. This clinical pathway may serve as an alternative or adjunct to arthrodesis and arthroplasty for young patients with severe posttraumatic osteoarthritis of the ankle and subtalar joint.</b> |                                    |                                     |                                                           |                                                     |                                 |
| 15. SUBJECT TERMS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                    |                                     |                                                           |                                                     |                                 |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                    |                                     | 17. LIMITATION OF ABSTRACT<br><b>Same as Report (SAR)</b> | 18. NUMBER OF PAGES<br><b>7</b>                     | 19a. NAME OF RESPONSIBLE PERSON |
| a. REPORT<br><b>unclassified</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | b. ABSTRACT<br><b>unclassified</b> | c. THIS PAGE<br><b>unclassified</b> |                                                           |                                                     |                                 |

**Figure 1**

Photograph of the Intrepid Dynamic Exoskeletal Orthosis. (Photograph courtesy of Kara L. Carrier, Medical Photographer, Brooke Army Medical Center, Fort Sam Houston, TX.)

muscle loss frequently complicate attempts at surgical management and rehabilitation.<sup>18-21</sup> A substantial proportion of musculoskeletal injuries are fractures, many of which are open. In the lower extremity, the tibia and fibula are most frequently affected.<sup>16</sup> Musculoskeletal injuries in combat-wounded service members account for significant medical resource utilization, but more importantly, they account for most long-term disability among those who are separated from active-duty service.<sup>22,23</sup>

PTOA is a substantial problem in the military. One study indicated

that 95% of unfitting OA diagnoses among combat-wounded service members are posttraumatic in origin.<sup>24</sup> Some of these patients request late amputation because of persistent disability.<sup>25,26</sup>

Recent reports have demonstrated the ability of combat-wounded patients to return to recreational sports activities after high-energy lower extremity trauma (HELET).<sup>21,27</sup> These persons participated in the Return To Run (RTR) clinical pathway. RTR is a high-intensity, sports medicine-based rehabilitation program in which participants are fitted with an Intrepid Dynamic Exoskeletal Orthosis (IDEO, Figure 1), a custom carbon fiber, energy storage and return ankle-foot orthosis.<sup>28</sup> Significant improvements in functional performance have been demonstrated in this primarily limb-salvage population using the IDEO compared with several commercially available orthoses ( $P < 0.008$ ).<sup>29</sup> These investigations have focused on a heterogeneous patient population, and no study to date has investigated the use of such a program in patients with PTOA of the ankle and subtalar joint. We evaluated the functional, occupational, and recreational capabilities of a cohort of military service members who sustained PTOA after HELET and who are enrolled in the RTR.

## Methods

The RTR database, which is not publicly available, contains informa-

tion on all persons who elected to participate in the program. The database was queried for all patients who were known to have PTOA of either the ankle or the subtalar joint. Patients who underwent tibiotalar or subtalar arthrodesis before enrollment in RTR were excluded from the study. Demographic information, including sex, age, and military rank, was collected for all patients. Information pertaining to each injury, such as mechanism of injury, original injury, desire for late amputation, and surgical management, was recorded. Latency time, that is, the length of time between the initial injury and the development of PTOA, was calculated. Outcomes were divided into functional, occupational, and recreational capabilities. Functional capabilities included ambulation without assistive devices other than the IDEO, ability to run any distance, and ability to jump. Occupational capabilities included return to duty, deployment or predeployment training, ability to stand for prolonged periods of time ( $\geq 1$  hour of continuous standing), and ability to move with a load weighing  $\geq 20$  pounds. Recreational capabilities included recreational running, agility sports participation, and mini triathlon participation (500-meter swim, 5-mile bike ride, and 2-mile run).

## Results

To date, 91 patients have been fitted with or are in the process of being fitted for an IDEO. Of these, 15 men

Mr. Owens or an immediate family member serves as an unpaid consultant to Twin Star Medical. Dr. Kirk or an immediate family member serves as a board member, owner, officer, or committee member of the American Orthopaedic Foot and Ankle Society. Dr. Hsu or an immediate family member has received research or institutional support from The Geneva Foundation, Combat Casualty Care Research Program, and the Major Extremity Trauma Research Consortium (METRC) and serves as a board member, owner, officer, or committee member of the Society of Military Orthopaedic Surgeons, the Limb Lengthening Research Society, the Orthopaedic Trauma Association, METRC, the Skeletal Trauma Research Consortium, and the American Academy of Orthopaedic Surgeons. Neither of the following authors nor any immediate family member has received anything of value from or has stock or stock options held in a commercial company or institution related directly or indirectly to the subject of this article: Dr. Patzkowski and Mr. Blanck.

**Table 1****Demographic Information on 16 Patients in the Return To Run Clinical Pathway**

| Patient No. | Age (yr) | Musculoskeletal Injury                                                                                                                                  | MOI           | Joint Affected by PTOA | PTOA Latency <sup>a</sup> (mo) |
|-------------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|------------------------|--------------------------------|
| 1           | 24       | Open talar body and ankle fracture                                                                                                                      | MCC           | TT                     | 18                             |
| 2           | 29       | Ankle fracture                                                                                                                                          | Explosion/MVC | ST                     | 9                              |
| 3           | 31       | Bilateral tibia fracture, pilon fracture                                                                                                                | Gunshot       | TT, ST                 | 4                              |
| 4           | 22       | Tibia fracture, multiple midfoot fractures, talonavicular dislocation, T12 burst fracture                                                               | Explosion/MVC | TT                     | 11                             |
| 5           | 26       | Calcaneus fracture                                                                                                                                      | Explosion/MVC | ST                     | 7                              |
| 6           | 40       | Open ankle fracture-dislocation, talus fracture                                                                                                         | Plane crash   | TT                     | 6                              |
| 7           | 24       | Bilateral ankle fracture, both-bone forearm fracture                                                                                                    | Explosion     | TT (bilateral)         | 11                             |
| 8           | 33       | Talus fracture, navicular fracture, hip dislocation, pelvic ring injury                                                                                 | Explosion/MVC | TT                     | 10                             |
| 9           | 25       | Calcaneus fracture, talus fracture, ankle fracture, L2 compression fracture, T5 compression fracture, open finger fracture, open humerus fracture       | Explosion/MVC | ST                     | 17                             |
| 10          | 37       | Pilon fracture                                                                                                                                          | MV vs Ped     | TT                     | 42                             |
| 11          | 24       | Open pilon fracture, open calcaneus fracture, talus fracture, calcaneocuboid dislocation                                                                | Explosion     | ST                     | 9                              |
| 12          | 27       | Open ankle fracture dislocation, calcaneus fracture, multiple midfoot fractures                                                                         | Explosion     | ST                     | 4                              |
| 13          | 30       | Calcaneus and talus fracture                                                                                                                            | Gunshot wound | ST                     | 7                              |
| 14          | 26       | Talus fracture, ankle fracture, multiple metatarsal fractures, ulna shaft fracture, multiligamentous knee injury, T8/11/12 superior end plate fractures | Explosion     | TT                     | 10                             |
| 15          | 26       | Open ankle fracture                                                                                                                                     | MVC           | TT                     | 72                             |
| 16          | 30       | Pilon fracture, bilateral distal femur fracture, scaphoid fracture, olecranon fracture, burns to face and bilateral upper extremity                     | MVC           | TT                     | 26                             |

MCC = motorcycle collision, MOI = mechanism of injury, MV = motor vehicle, MVC = motor vehicle collision, Ped = pedestrian, PTOA = posttraumatic osteoarthritis, ST = subtalar, TT = tibiotalar

<sup>a</sup> Latency is calculated as the time between the initial injury and the original diagnosis of posttraumatic osteoarthritis.

and 1 woman were identified as having a known diagnosis of PTOA of the ankle or subtalar joint (18%). Average age at the time of injury was 28 years (range, 24 to 40 years), and average latency time was 16.4 months (range, 4 to 72 months). All 16 subjects sustained high-energy trauma (Table 1). Six of these 16 subjects initially expressed a desire to undergo late amputation (38%).

Since enrollment in the RTR, however, only one continues to request amputation. Five patients were treated with circular external fixation, and seven have undergone eight fusion procedures (four ankle, four subtalar). One patient developed tibiotalar ankylosis without surgical fusion.

Functional, occupational, and recreational capabilities are shown in

Table 2. With regard to functional capabilities, 94% of the 16 patients can ambulate without assistive devices, 81% can run, and 75% can jump. In the occupational setting, 44% have returned to active military duty, 13% have deployed to combat, 100% can stand for longer than 1 hour, and 69% can move with a load of  $\geq 20$  pounds. In terms of recreational pursuits, 69% of subjects

**Table 2****Functional, Occupational, and Recreational Capabilities of Patients Enrolled in the Return to Run Clinical Pathway**

| Patient No. | Amb | Run | Jump | RTD | D/PDT | Prol Stand | Load <sup>a</sup> | Rec Running | Agility Sports | Mini Tri |
|-------------|-----|-----|------|-----|-------|------------|-------------------|-------------|----------------|----------|
| 1           | X   | X   | X    |     |       | X          | X                 | X           | X              | X        |
| 2           | X   | X   | X    | X   |       | X          |                   | X           | X              |          |
| 3           |     |     |      |     |       | X          |                   |             |                |          |
| 4           | X   | X   | X    |     |       | X          | X                 | X           | X              | X        |
| 5           | X   | X   | X    |     |       | X          | X                 | X           | X              |          |
| 6           | X   | X   | X    | X   | X     | X          | X                 | X           | X              |          |
| 7           | X   | X   |      |     |       | X          |                   |             |                |          |
| 8           | X   | X   | X    |     |       | X          | X                 | X           | X              | X        |
| 9           | X   |     |      |     |       | X          | X                 |             |                |          |
| 10          | X   | X   | X    | X   |       | X          | X                 | X           | X              |          |
| 11          | X   | X   | X    |     |       | X          |                   |             |                |          |
| 12          | X   |     |      |     |       | X          |                   |             |                |          |
| 13          | X   | X   | X    | X   |       | X          | X                 | X           | X              |          |
| 14          | X   | X   | X    | X   |       | X          | X                 | X           | X              |          |
| 15          | X   | X   | X    | X   | X     | X          | X                 | X           | X              |          |
| 16          | X   | X   | X    | X   |       | X          | X                 | X           | X              |          |

Amb = ambulation without assistive devices, D/PDT = deployment or predeployment training, Mini Tri = mini triathlon, Prol Stand = prolonged standing, Rec Running = recreational running, RTD = return to duty

<sup>a</sup> Ability to move with a load of  $\geq 20$  pounds

run, 69% participate in agility sports, and 19% have completed the mini triathlon.

## Discussion

Arthrodesis is the standard of care for managing end-stage ankle and subtalar PTOA. Although consistent pain relief and improved outcomes have been reported, the procedure is also associated with altered gait mechanics as well as ipsilateral foot and subtalar joint degeneration.<sup>30-32</sup> Long-term studies demonstrate that ipsilateral arthrosis is functionally limiting; however, most patients report that they would undergo arthrodesis again, and most would recommend the procedure to a friend under similar circumstances.<sup>31,32</sup> Total ankle arthroplasty is a viable option in elderly persons, but it is typically avoided in patients younger than 60 years because of concerns re-

garding accelerated implant wear with higher-impact activities as well as high complication rates.<sup>2,30,33-35</sup>

Current strategies to prevent PTOA are focused on restoration of joint congruity and stability.<sup>3-5,9</sup> Efforts are underway to use pharmacologic management to halt or reverse the apoptotic cascade initiated within chondrocytes following direct blunt trauma to the articular surface.<sup>11,36</sup> Few reports have focused on specific rehabilitation therapies for young, active patients with PTOA following HELET.<sup>21,27,28</sup>

Ours is the first report to investigate the nature of ankle and subtalar PTOA in high-energy military trauma. The rate of PTOA among the limb-salvage patients enrolled in the RTR clinical pathway is 18%. All patients sustained their injuries as the result of severe high-energy trauma. Most sustained multiple injuries to the lower extremities, and

many had associated injuries to the contralateral lower extremity, upper extremity, and organ systems. Such severe injuries are not readily encountered in the civilian trauma setting. Despite the severity of their injuries, many persons in our cohort are returning to participation in recreational sports, returning to military duty, and deploying to combat. Nearly 40% of these patients initially requested amputation of their injured limb because of pain and activity limitations, but since being enrolled in the RTR, 83% have countermanded the request.

The prevalence of PTOA in a military population is currently unknown. In a cohort of combat casualties referred for medical separation from active-duty service, 29.6% of service members were found to have at least one unfitting condition related to arthritis.<sup>24</sup> Of these, 95% were directly attributable to the com-



bat injury, whereas only 5% resulted from injuries sustained before combat deployment. Nearly one quarter of the arthritis cases involved the foot or ankle, and most of the ankle injuries in the overall cohort led to unfitting arthritis.

Our patient population is unique, and the severe high-energy mechanisms of injury reported here are not typically found in the civilian trauma setting. In a retrospective series, Horisberger et al<sup>7</sup> reported average latency times of 40.9 years for diaphyseal tibia fractures, 21.5 years for pilon fractures, and 21.1 years for malleolar fractures. This is substantially longer than the 16 months reported here. This difference is likely the result of the higher-energy mechanisms of injury encountered in a combat environment compared with mechanisms typically seen in civilian trauma centers.

The RTR clinical pathway is currently in use only at our institution, but an effort is underway to build the capability for the program at other military treatment facilities and collaborating civilian trauma centers. The high-intensity, progression-oriented rehabilitation program challenges patients early in their recovery.<sup>21,27,28</sup> Performance in the program is facilitated by the IDEO. This orthosis provides a significant improvement in functional performance and is well tolerated in the short term.<sup>29</sup> The device is designed to off-load painful segments of the lower extremity. Because the device is custom-fabricated for each patient, the area of off-loading differs with each device.

The RTR clinical pathway has been in operation for only 2 years, and the long-term effects of wearing the IDEO and participating in this rehabilitation program are not well understood. In particular, it is not known whether long-term off-loading of painful segments of the limb may accelerate or de-

celerate adjacent joint degeneration. Despite this limitation, we believe that this structured multidisciplinary approach, which requires close collaboration between orthopaedic surgeons, physical therapists, and orthotists, provides an interesting alternative to arthrodesis and arthroplasty in young, active patients with PTOA of the ankle and subtalar joint.

## Summary

PTOA is a substantial problem in US civilian and military populations. Arthrodesis and arthroplasty are not always desirable in the young, active patient with PTOA of the ankle or hindfoot. Use of an integrated orthotic and rehabilitation initiative in combat-wounded military personnel has allowed many of these patients to return to military duty and recreational sporting activities. Additional effort should be directed toward rehabilitation and improved orthotic strategies to maximize the functional performance of these patients. Further prospective study of this treatment protocol in a large, civilian population may provide valuable insights into the optimal postoperative treatment regimen for persons with these severe injuries.

## References

1. American Academy of Orthopaedic Surgeons: *The Burden of Musculoskeletal Diseases in the United States: Prevalence, Societal and Economic Cost*. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2008.
2. Anderson DD, Chubinskaya S, Guilak F, et al: Post-traumatic osteoarthritis: Improved understanding and opportunities for early intervention. *J Orthop Res* 2011;29(6):802-809.
3. Buckwalter JA: Sports, joint injury, and posttraumatic osteoarthritis. *J Orthop Sports Phys Ther* 2003;33(10):578-588.
4. Buckwalter JA, Brown TD: Joint injury, repair, and remodeling: Roles in post-

traumatic osteoarthritis. *Clin Orthop Relat Res* 2004;(423):7-16.

5. Furman BD, Olson SA, Guilak F: The development of posttraumatic arthritis after articular fracture. *J Orthop Trauma* 2006;20(10):719-725.
6. Giannoudis PV, Tzioupis C, Papathanassopoulos A, Obakponovwe O, Roberts C: Articular step-off and risk of post-traumatic osteoarthritis: Evidence today. *Injury* 2010;41(10):986-995.
7. Horisberger M, Valderrabano V, Hintermann B: Posttraumatic ankle osteoarthritis after ankle-related fractures. *J Orthop Trauma* 2009;23(1):60-67.
8. Martin JA, Buckwalter JA: Post-traumatic osteoarthritis: The role of stress induced chondrocyte damage. *Biorheology* 2006;43(3-4):517-521.
9. McKinley TO, Rudert MJ, Koos DC, Brown TD: Incongruity versus instability in the etiology of posttraumatic arthritis. *Clin Orthop Relat Res* 2004;(423):44-51.
10. Murray MM, Zurakowski D, Vrahas MS: The death of articular chondrocytes after intra-articular fracture in humans. *J Trauma* 2004;56(1):128-131.
11. Szczodry M, Coyle CH, Kramer SJ, Smolinski P, Chu CR: Progressive chondrocyte death after impact injury indicates a need for chondroprotective therapy. *Am J Sports Med* 2009;37(12):2318-2322.
12. Huch K: Knee and ankle: Human joints with different susceptibility to osteoarthritis reveal different cartilage cellularity and matrix synthesis in vitro. *Arch Orthop Trauma Surg* 2001;121(6):301-306.
13. Huch K, Kuettner KE, Dieppe P: Osteoarthritis in ankle and knee joints. *Semin Arthritis Rheum* 1997;26(4):667-674.
14. Brown TD, Johnston RC, Saltzman CL, Marsh JL, Buckwalter JA: Posttraumatic osteoarthritis: A first estimate of incidence, prevalence, and burden of disease. *J Orthop Trauma* 2006;20(10):739-744.
15. Saltzman CL, Salamon ML, Blanchard GM, et al: Epidemiology of ankle arthritis: Report of a consecutive series of 639 patients from a tertiary orthopaedic center. *Iowa Orthop J* 2005;25:44-46.
16. Owens BD, Kragh JF Jr, Macaitis J, Svoboda SJ, Wenke JC: Characterization of extremity wounds in Operation Iraqi Freedom and Operation Enduring Freedom. *J Orthop Trauma* 2007;21(4):254-257.
17. Owens BD, Kragh JF Jr, Wenke JC, Macaitis J, Wade CE, Holcomb JB:

- Combat wounds in operation Iraqi Freedom and operation Enduring Freedom. *J Trauma* 2008;64(2):295-299.
18. Shawen SB, Keeling JJ, Branstetter J, Kirk KL, Ficke JR: The mangled foot and leg: Salvage versus amputation. *Foot Ankle Clin* 2010;15(1):63-75.
  19. Ursone RL: Unique complications of foot and ankle injuries secondary to warfare. *Foot Ankle Clin* 2010;15(1):201-208.
  20. Grogan BF, Hsu JR; Skeletal Trauma Research Consortium: Volumetric muscle loss. *J Am Acad Orthop Surg* 2011; 19(suppl 1):S35-S37.
  21. Owens JG: Physical therapy of the patient with foot and ankle injuries sustained in combat. *Foot Ankle Clin* 2010;15(1):175-186.
  22. Cross JD, Ficke JR, Hsu JR, Masini BD, Wenke JC: Battlefield orthopaedic injuries cause the majority of long-term disabilities. *J Am Acad Orthop Surg* 2011;19(suppl 1):S1-S7.
  23. Masini BD, Waterman SM, Wenke JC, Owens BD, Hsu JR, Ficke JR: Resource utilization and disability outcome assessment of combat casualties from Operation Iraqi Freedom and Operation Enduring Freedom. *J Orthop Trauma* 2009;23(4):261-266.
  24. Cross JD, Johnson AE: Impact of traumatic arthritis on a cohort of combat casualties. *78th Annual Meeting Proceedings*. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2011, p 566.
  25. Huh J, Stinner DJ, Burns TC, Hsu JR; Late Amputation Study Team: Infectious complications and soft tissue injury contribute to late amputation after severe lower extremity trauma. *J Trauma* 2011;71(1 suppl):S47-S51.
  26. Stinner DJ, Burns TC, Kirk KL, et al: Prevalence of late amputations during the current conflicts in Afghanistan and Iraq. *Mil Med* 2010;175(12):1027-1029.
  27. Owens JG, Blair JA, Patzkowski JC, Blanck RV, Hsu JR; Skeletal Trauma Research Consortium: Return to running and sports participation after limb salvage. *J Trauma* 2011;71(1 suppl): S120-S124.
  28. Patzkowski JC, Blanck RV, Owens JG, Wilken JM, Blair JA, Hsu JR: Can an ankle-foot orthosis change hearts and minds? *J Surg Orthop Adv* 2011;20(1):8-18.
  29. Patzkowski JC, Blanck RV, Owens JG, et al: Comparative effect of orthosis design on functional performance. *J Bone Joint Surg Am* 2012;94(6):507-515.
  30. Kozanek M, Rubash HE, Li G, de Asla RJ: Effect of post-traumatic tibiotalar osteoarthritis on kinematics of the ankle joint complex. *Foot Ankle Int* 2009; 30(8):734-740.
  31. Coester LM, Saltzman CL, Leupold J, Pontarelli W: Long-term results following ankle arthrodesis for post-traumatic arthritis. *J Bone Joint Surg Am* 2001;83(2):219-228.
  32. Fuchs S, Sandmann C, Skwara A, Chylarecki C: Quality of life 20 years after arthrodesis of the ankle: A study of adjacent joints. *J Bone Joint Surg Br* 2003;85(7):994-998.
  33. Kitaoka HB, Patzer GL: Clinical results of the Mayo total ankle arthroplasty. *J Bone Joint Surg Am* 1996;78(11):1658-1664.
  34. Spirt AA, Assal M, Hansen ST Jr: Complications and failure after total ankle arthroplasty. *J Bone Joint Surg Am* 2004;86(6):1172-1178.
  35. Bolton-Maggs BG, Sudlow RA, Freeman MA: Total ankle arthroplasty: A long-term review of the London Hospital experience. *J Bone Joint Surg Br* 1985; 67(5):785-790.
  36. Lotz MK, Kraus VB: New developments in osteoarthritis: Posttraumatic osteoarthritis. Pathogenesis and pharmacological treatment options. *Arthritis Res Ther* 2010;12(3):211.