· 专家共识 ·

严重开放性肢体创伤早期救治专家共识

朱庆棠[1]　李文军[2]　朱磊[3]　郑宪友[4]　吴攀峰[5]　钟刚[6]　黄喜军[1]　邓佩军[1]

[1]中山大学附属第一医院,广州　510080;[2]北京积水潭医院,北京　100035;[3]山东大学齐鲁医院,济南　250012;[4]上海交通大学附属第六人民医院,上海　201103;[5]中南大学湘雅医院,长沙　410013;[6]四川大学华西医院,成都　610044

通讯作者:朱庆棠,Email:zhuqingt@mail.sysu.edu.cn,电话:+86 20 8761 8242

DOI: 10.3760/cma.j.cn441206-20221010-00207

严重开放性肢体创伤常见于高能量损伤,累及多种组织结构,损伤程度重,可能影响肢体成活甚至危及生命,对肢体功能有严重影响。对于此类创伤,无论是伤情评估、治疗决策,还是救治的实施,都面临巨大挑战,对急救的时限要求高,对救治团队技术水平和医疗机构综合救治能力的要求也比较高,需具备较强的伤情判断与监测、损伤控制、生命支持、组织修复重建以及并发症防治的能力[1]。此类患者受伤后通常被送往就近的基层医院进行急救,有不少患者经多次转诊才到达具备救治能力的医院进一步处理,往往错过最佳救治时机;而有的患者因种种原因未能及时接受规范治疗,丧失了保肢机会或后遗严重的肢体残疾[2]。

本共识围绕严重开放性肢体创伤早期救治的需求,对伤情评估与急救、治疗决策、肢体血液循环重建、骨关节固定、创面处理等提出基本原则和建议,供临床医生在实际诊疗过程中参考使用,为分级、分类及时规范救治提供专业意见。

本共识聚焦于严重开放性肢体创伤早期救治,闭合性损伤、多发伤伴肢体创伤、肢体完全离断的救治,以及肢体Ⅱ期修复与功能重建等内容不在本共识范畴。

一、严重开放性肢体创伤的定义

严重开放性肢体创伤是指高能量暴力所致的上肢或下肢损伤,有开放伤口,累及多种组织,伤情严重,可能危及生命或影响患肢成活[1]。诊断为严重开放性肢体创伤有 3 个必要条件:①属于高能量损伤;②有开放伤口且累及多种组织;③有即时生命危险或危及肢体成活,对肢体功能有严重影响,需要紧急规范救治。高能量暴力导致的大面积皮肤脱套、软组织缺损、四肢主干血管损伤、Gustilo IIIB/IIIC 型骨折等,都属于严重开放性肢体创伤。

二、严重开放性肢体创伤的评估

(一)现场评估与院前急救

1.全身评估:在受伤现场,需迅速排查是否存在危及生命的伤情,首先检查生命体征、神志、瞳孔,然后按 CRASHPLAN 字母顺序检查,其分别为以下名词首字母:Cardiac(心脏)、Respiratory(呼吸)、Abdomen(腹部)、Spine(脊柱)、Head(头颅)、Pelvis(骨盆)、Limbs(四肢)、Arteries(动脉)和 Nerves(神经),给予基础生命支持(Basic life support,BLS)[3]。

2.伤肢评估:现场还要排查是否存在危及肢体成活的伤情,重点检查肢端血液循环(皮肤颜色和温度、动脉搏动、毛细血管回充盈反应)、神经功能(运动、感觉)、伤口(出血、污染、组织缺损等)、骨关节稳定性[4]。

3.现场急救:如果有活动性出血,应该进行创面加压包扎止血,对于难以控制的大血管损伤出血,必要时可以使用止血带,但需严格控制压力和止血带时间,单次使用时间不超过 2 h[5-6]。对于有关节脱位的肢体,应该第一时间尝试复位,但污染严重的开放性骨折不主张在急救现场进行复位。有条件的情况下可以在急救现场对污染创面进行简单清洗,无菌敷料覆盖创面,简易夹板固定伤肢,固定时应该超过骨折的邻近上、下关节,同时注意避免血管、神经受到压迫[7]。没有条件时,可以就地取材,做好包扎、止血与固定。

(二)院内评估

1.全身和局部评估:严重开放性肢体创伤患者经过现场急救处理,到达医院后应该再次评估全身和局部情况,遵照高级创伤生命支持(Advanced trauma life support, ATLS)[8]和损伤控制骨科(Damage control orthopedics, DCO)的原则与方法实施评估与急救[9-11]。

2.影像学评估:主要包括血管影像学检查和骨关节影像学检查。对于怀疑有肢体动脉损伤者,在生命体征

平稳情况下应该立即进行血管超声或 CT 血管造影(Computed tomographic angiography,CTA),必要时可行血管造影数字减影成像(Digital subtraction angiography, DSA)检查[12-13]。肢体骨关节影像学检查包括骨折部位以及上、下邻近关节 X 线片,关节内及关节周围骨折应该行CT 三维重建检查。但需注意,不能因为影像学检查而延误抢救生命或肢体缺血的处理[14]。

3.肢体损伤严重程度评估:可以采用肢体损伤严重程度性评分系统(Mangled Extremity Severitiy Score, MESS)[15](表 1)。

表 1 MESS 评分量表

项目	分级	得分
骨骼软组织损伤程度	低能量	1
	中能量	2
	高能量	3
	广泛挤压伤	4
休克程度	血压正常	1
	暂时低血压	2
	长时间低血压	3
局部缺血程度	无(脉搏和灌注正常)	0
(缺血时间>6 h,分值加倍)	轻(脉搏减弱但灌注正常)	1
	中(无脉搏)	2
	重(无脉搏且皮温冷,麻痹)	3
年龄(岁)	<30	0
	30~50	1
	>50	2

4.心理社会因素评估:严重开放性肢体创伤由于伤情严重,医疗费用和预后都难以估计,患者及家属往往都会存在心理应激障碍。应该对患者及家属进行心理因素评估和疏导,评估考虑患方能获取社会支持、积极进行医疗救治的能力,同时考虑患者的民族、宗教信仰等因素。

(三)术中评估

严重开放性肢体创伤患者在完成高级生命支持和初期肢体严重度评估后, 需要进入手术室进一步清创处理,清创的过程中应该再次对受伤肢体进行评估[16]。①创面与皮肤:注意检查创口范围、深度、污染情况,皮肤活力,特别注意是否有皮肤脱套或潜行剥脱,皮肤缺损情况。②肌肉与肌腱:根据“4C”指标判断肌肉活力,即颜色(Colour)、收缩性(Contractibility)、肌肉连续性(Consistency)、供血状况(Capacity of Blood)。检查肌腱是否完整,特别注意是否有肌腱-肌腹交界处撕脱,或肌腱近断端回缩至肌腹内。③血管与神经:检查血管、神经的连续性,是否有血管挫伤、血栓形成或血管破裂、断裂;神经是否有挫伤、断裂。④骨与关节:检查骨、关节稳定性,是否有骨折和(或)关节脱位,骨折粉碎程度、骨折块大小、游离及污染程度。对于开放性骨折者,应在清创术后根据 Gustilo-Anderson 分型[17]或改良 Gustilo-Anderson 分型标准[18]进行评估。

三、严重开放性肢体创伤的治疗决策

严重开放性肢体创伤可能危及肢体成活,早期救治需首先作出是否保肢的决策[19-20]。对于 MESS≤7 分者,应尽可能保肢;对于 MESS>7 分者,需综合分析伤情、救治条件、患者意愿等,决定是否保肢[2,21-22]。

严重开放性肢体创伤行截肢治疗的指征应严格掌握,原则上需要经骨显微外科专科医生会诊[23-24],确认不宜或无法保肢再行截肢手术[25];如接诊医院不具备实施保肢治疗的条件,应及时将患者转运至有保肢能力的医院,除非因患者原因不适合转运[26]。

对于严重开放性肢体创伤选择保肢治疗[27],需具备以下条件:①生命体征稳定,重要脏器功能无明显障碍,患者能耐受保肢治疗;②重建血液循环后,损伤的肢体能成活;③预期经修复重建手术后,肢体可恢复一定功能;④患者、家属有强烈的保肢意愿,有充分的支撑保障条件,依从性好,能全程配合治疗。

对于具体的患者,是否保肢,需综合考虑医、患双方的情况作出个性化选择[28]。

四、严重开放性肢体创伤早期救治原则

1.生命第一:严重开放性肢体创伤早期救治最重要的任务是保命,可按照ATLS 和 DCO 的原则与方法实施评估与急救。

2.预防“缺血-坏死-感染”恶性循环:严重开放性肢体创伤面临组织缺血、坏死、感染的风险非常高,且三者互相影响,形成恶性循环。肢体遭受严重创伤后,无论是全身循环血量重新分布,还是局部血管损伤,或发生骨筋膜室综合征,都会导致组织灌注不足,缺血、缺氧而发生坏死;暴力直接作用也会造成组织坏死,引起局部甚至全身炎症反应,加重组织缺血、缺氧;开放性损伤时皮肤屏障被破坏,病原微生物侵入,容易造成感染,组织缺血削弱了机体对微生物的清除能力,且坏死组织成为滋养微生物的温床,加速感染的发生发展。因此,严重开放性肢体创伤早期救治必须及时恢复或改善组织灌注,及时、彻底清除坏死组织,及时关闭伤口。

3.肢体血液循环优先:在保命的前提下尝试保肢,

其核心是维持肢体血液循环。对于影响肢体血供的主干动脉损伤,必须优先修复[29],其伴行静脉也要修复;发生骨筋膜室综合征者,必须及时行筋膜切开,充分减压[30-31],争取将缺血时间控制在 6~8 h[32-33]。

4.稳定骨和关节结构:对于骨折及关节脱位患者,尽可能恢复肢体长度和力线后给予稳定的固定;对于Gustilo III C 型骨折且有大面积软组织缺损者,通常首选外固定支架,软组织条件许可时可谨慎实施有限内固定。对于关节内骨折,要争取达到良好的复位和固定。对于行血管修复或大面积软组织缺损患者,建议使用外固定支架维持肢体稳定性,稳定的骨、关节结构有利于保护血管和后期创面修复。

5.神经、肌肉、肌腱修复:严重肢体创伤彻底清创后,应尽可能一期修复神经、肌肉与肌腱;对于污染严重难以一次彻底清创者,往往也难以实现Ⅰ期修复,建议Ⅱ期亚急诊再次彻底清创后修复,并实现创面的有效覆盖。

6.及时覆盖创面:及时覆盖创面是预防感染、减少并发症的重要手段。可根据患者全身和局部情况选择临时性覆盖还是确定性修复。

五、清创

1.清创的总体原则:清创是处理严重开放性肢体创伤的重要措施[16,34],是肢体功能重建与恢复的基础,再怎么强调都不为过。具体实施时,宜遵循以下原则:①只要患者全身情况允许,对创口的清创就必须及时进行,尤其在出现创口严重污染(水产、农业、污水等)、筋膜间室综合征早期症状或合并血管损伤等情况时[35-36],更需要争分夺秒尽早实施;②让经验丰富的医生清创,有助于更仔细彻底的清创,可改善患者的预后[2,37];③遵循无菌和微创的原则;④彻底清除创口异物、切除失活组织、彻底止血,使之尽可能变成清洁伤口;⑤在彻底清创的基础上,尽可能实现创面的早期闭合,但对在海水、农田或下水道等特殊环境中受伤,或人畜咬伤、热压伤等特殊类型的损伤,一期只做清创术,24~48 h 内对软组织和骨组织实施再次探查,以清除继发坏死和(或)感染组织,有时甚至需进行反复多次的清创。

2.清创的术前必要准备:①器械准备:无菌手术包、生理盐水、肥皂水、络合碘和止血带等;②预防性应用抗生素[38-39],在围术期用足量有效抗生素;③注射破伤风抗毒素[37],轻者用 1 500 U,重者用 3 000 U;④良好的麻醉;⑤建议使用止血带,在无血的视野下进行。

3.清创的方法与步骤:(1)无菌敷料覆盖创面后肥皂水清洗患肢,常规消毒。(2)清除异物、污染的软组织,尤其是失活组织。(3)必要时需延长切口,直至显露出比较清洁和血运良好的组织。(4)清创的时候应该“地毯式”地由浅入深、由外及里、循序进行,需彻底清除异物、污染物以及失活的皮肤、脂肪、肌肉和骨骼,避免创面的交叉污染。①皮肤:根据皮缘出血情况判断皮肤活力。首先对创缘做必要的修整;对于有明显挤压、碾挫痕迹的撕脱皮肤,为避免后患,态度积极的去除;撕脱皮肤挫伤轻,深面肌肉组织和骨膜血运良好,可将撕脱皮肤反取皮回植,并在回植皮肤上采用与肢体关节运动轴相平行的多个小切口引流。②肌肉:通过“4C 原则”判断肌肉活力。③血管:对明显损伤的动脉,应作彻底切除,甚至疑有损伤的部分也应切除,以免后期形成血栓和吻合口裂开等危险。不可为了方便仅行血管单纯修复术,或顾虑切除太多端端吻合困难而留下已有损伤的管壁组织,从而导致血管修复术的失败。④神经:切除污染的神经外膜,修剪整齐神经断端,尽可能Ⅰ期无张力缝合修复,如果无法Ⅰ期修复,可先标记断端,留待Ⅱ期修复。⑤肌腱:切除污染的肌腱表层组织和长短不一的肌腱纤维,原则上肌腱应尽可能Ⅰ期修复,但如果没有Ⅰ期修复的条件,可先标记断端,留待Ⅱ期修复。⑥骨与关节:根据骨面渗血情况判断骨块的活力,对于粉碎骨块的处理仍有争议,有良好软组织相连、骨折块有血运的可予以保留;若完全游离,必须在彻底清创且有良好软组织覆盖的前提下,才可以保留[40-41];Masquelet 技术[42]、肢体Ⅰ期短缩Ⅱ期延长技术[43]、骨搬移技术[44]和皮肤牵张技术[45-46]的治疗周期漫长,可以在与患者及家属充分沟通的基础上酌情选择。(5)冲洗伤口:严重开放性肢体创伤经彻底清创后应常规进行冲洗,目的是清除污染物、组织碎屑、血肿,减少创面的细菌载荷,从而降低感染风险。伤口冲洗推荐使用生理盐水,用量必须充分。对于 Gustilo Ⅰ型、Ⅱ型、Ⅲ型开放性骨折,冲洗量需分别达到 3 升、6 升和 9 升[47]。新鲜伤口可考虑采用脉冲式冲洗[48],陈旧性或慢性感染伤口不推荐枪式脉冲方式冲洗。

六、血液循环重建

1.血管损伤的分型与修复方法:严重开放性肢体创伤中的血管损伤,常伴有严重的软组织损伤。损伤血管周围软组织的情况对修复方法选择及结局影响大,需根据损伤血管的软组织覆盖情况选择不同的修复策略[49]。

Ⅰ型:损伤血管有健康的软组织覆盖,可根据其病理类型的不同,选择切开取栓、损伤段血管切除吻合或血管移植、腔内治疗等[50-51]。对于肢体动脉缺损应首选

自体静脉移植,人工血管应慎用。

II 型:损伤血管无软组织覆盖,需行 Flow-through 皮瓣移植修复或静脉移植的同时予肌(皮)瓣覆盖。

III 型:血管损伤区广泛,边界不清,或继发严重坏死、感染。可行健侧肢体血管转位患肢原位寄养,Ⅱ期重建血管;或将带主干动、静脉的轴型皮瓣制成皮管,跨血管损伤区进行移植桥接[52]。

2.重建血液循环的特殊方法:对于预期缺血时间超过 6 h 者,可采用临时性血管转流技术[53-56],恢复肢体远端血供,再行清创、探查、骨折固定等操作。

3.骨筋膜室综合征的处理:严重开放性肢体创伤也可能发生急性骨筋膜室综合征。一旦发现患者有骨筋膜室综合征,应及时、充分行筋膜切开减压[57-59]。对于热缺血时间超过 8 h 者,需常规行预防性筋膜切开术[60]。

七、骨及关节损伤的处理

1.骨及关节复位固定原则:骨及关节复位固定的主要目的是提供足够的机械稳定性、减少并发症发生,具体方案取决于患者的全身情况、骨折类型及软组织条件等。经过彻底清创和软组织覆盖良好的患者,可考虑行Ⅰ期内固定治疗[61-62];但严重开放性肢体创伤常伴有严重的软组织损伤,骨折部位软组织覆盖条件差,甚至全身情况不稳定,推荐Ⅰ期行临时外固定治疗,注意恢复骨折肢体力线和维持关节面完整[63]。

2.骨折固定时机和方法:在全身情况稳定、骨折部位彻底清创后软组织覆盖良好的条件下,可以在伤后 6~8 h 内进行Ⅰ期内固定治疗[64]。如能在伤后 48~72 h 内完成对创面良好的软组织覆盖,也可考虑Ⅰ期内固定。

根据损伤部位选择钢板、螺钉或髓内钉[65-67]。①钢板、螺钉固定:适合关节内和干骺端骨折,需要维持关节面的完整和骨折对位、对线的复位。可以使用多个钢板或空心螺钉辅助,提高骨折固定的稳定性。可吸收材料或记忆合金也适用于骨折的固定。手术中注意保护骨折端和大骨块的血供,完全没有血运的骨块不建议直接丢弃,在彻底清创、没有污染的情况下可以予以复位固定,利用血供良好的软组织覆盖,可以获得良好的支撑和愈合[40]。②髓内钉固定:对于下肢骨干骨折,髓内钉应慎用[68],不建议扩髓[69],髓内钉植入过程要特别谨慎,切口经感染部位或者有污染,有可能引起严重的髓内感染,导致截肢的严重后果[70]。

对于不宜Ⅰ期内固定治疗者,予以临时外固定,Ⅱ期转为确定性固定。对于情况稳定、无全身炎症反应、钉道无感染、软组织条件良好的患者,建议术后 14 d 内尽早转为确定性内固定[71-72];对于伤口污染严重、有潜在感染风险、超过 14 d 仍不满足以上条件者,可考虑更换为终末外固定架保持到骨折愈合。或者再次清创,等待软组织条件改善后再行确定性内固定。

3.骨缺损的处理:骨缺损的修复包括游离骨移植、骨搬运以及带血管蒂的骨移植等技术[73-76]。游离骨移植一般适用于小于 2 cm 的骨缺损;利用显微外科技术移植带血运的骨瓣或与组织瓣联合移植,可以有效的解决大段骨缺损和软组织覆盖问题。大块的骨质缺损可以用抗生素骨水泥填充,或者根据软组织情况将骨质短缩固定,Ⅱ期行确定性修复[45]。

八、创面覆盖

1.创面覆盖的原则:对于严重开放性肢体创伤早期创面覆盖,建议送到既能处理骨折又能修复软组织缺损的医疗单位或专科救治中心,譬如骨显微中心进行处理[77-78]。

2.创面覆盖的时机:①尽可能Ⅰ期覆盖创面。必须在患者血流动力学稳定、清创彻底、无可预见的骨及软组织感染的前提下进行。②必要时延迟闭合创面。对于合并其他重要脏器损伤以及患者血流动力学不稳定等情况下,出于损伤控制等目的,创面可以采用负压封闭引流敷料临时覆盖[79],具体以患者的实际情况酌情选择,但需要在 3~7 d 内实现创面的确定性覆盖[80-83];如存在怀疑气性坏疽或创面止血不彻底,应杜绝使用负压封闭引流。此外,不提倡反复多次使用负压封闭引流[84-87]。

3.创面覆盖的方法:对于严重开放性肢体创伤,早期闭合创面能有效降低感染率和促进骨折的愈合[16,88-91]。具体软组织修复重建建议如下:①若清创后没有明显软组织缺损的情况,可直接缝合或减张缝合;如皮肤缺损但没有深部组织裸露,可采用游离皮片移植修复;有小面积骨或肌腱外露的创面,如无需Ⅱ期进行深部组织修复重建,可采用局部皮瓣或筋膜瓣修复,或采用人工真皮覆盖创面。②对于肢体血运有保障的严重开放性肢体创伤,如撕脱皮肤挫伤轻,深面肌肉组织和骨膜血运良好,可将撕脱皮肤反取皮回植;撕脱皮肤挫伤严重,估计撕脱皮肤会出现坏死,应态度积极地去除直至皮肤血运可靠,可急诊或亚急诊选择游离皮瓣覆盖骨外露创面[92-93];伴有大面积软组织缺损时,单个皮瓣难以直接覆盖肌腱或骨外露创面,可以选择肌(皮)瓣修复骨外露和肌腱外露创面,残余肌肉创面给予敷料临时性覆盖或植皮[94];对于伴有多种组织缺损的复杂创面,可选择带多种组织的嵌合皮瓣予以修复。③对于软组织损伤严重者,尽量避免选择局部带血管蒂

皮瓣覆盖创面。④对于 Gustilo III C 型的肢体创伤,I 期血管移植重建肢体血运,如血管外露于创面,可 I 期行游离皮瓣、带血管蒂肌瓣或 Flow-through 皮瓣覆盖[52,95]。在皮瓣选择方面,应充分利用股前外侧皮瓣和背阔肌皮瓣[93,96-97]以及传统的小腿内侧皮瓣[98-99]。

免责声明 本共识仅供同行参阅及专科医师作为显微外科、创伤骨科、修复重建外科等专业的技术参考,不能将其作为绝对标准,更不作为法律依据,不具备法律效力,不作为任何医疗纠纷处理选择的法律法规依据。其中的原则也是灵活的。而且,本共识具有时限性,会随着将来有更高级更充分的研究证据和理论的出现而更新修改

共识专家组成员(按姓氏汉语拼音顺序排列)

陈振兵(华中科技大学同济医学院附属协和医院)、顾立强(中山大学附属第一医院)、侯春林(海军军医大学长征医院)、侯建玺(郑州仁济医院)、刘小林(中山大学附属第一医院)、唐举玉(中南大学湘雅医院)、汪华侨(《中华显微外科杂志》编辑部)、王欣(宁波市第六医院)、徐永清(解放军联勤保障部队第九二〇医院)、喻爱喜(武汉大学中南医院)、张长青(上海交通大学附属第六人民医院)、赵广跃(空军军医大学附属西京医院)、郑晓菊(西安凤城医院手足显微外科病院)

利益冲突 所有作者均声明不存在利益冲突

参 考 文 献

[1] Bumbaširević M, Matić S, Palibrk T, et al. Mangled extremity-modern concepts in treatment[J]. Injury,2021,52(12):3555-3560. DOI:10.1016/j.injury.2021.03.028.

[2] Sharrock M. The mangled extremity: Assessment, decision making and outcomes[J]. Acta Orthop Belg,2021,87(4):755-760. DOI:10.52628/87.4.22.

[3] The National Institute for Health and Care Excellence(NICE). Major Trauma: Assessment and Initial Management[J]. 2016.

[4] Shafiq B, Hacquebord J, Wright DJ, et al. Modern principles in the acute surgical management of open distal tibial fractures[J]. J Am Acad Orthop Surg,2021,29(11):e536-e547. DOI:10.5435/JAAOS-D-20-00502.

[5] Jensen J, Hicks RW, Labovitz J. Understanding and optimizing tourniquet use during extremity surgery[J]. AORN J,2019,109(2):171-182. DOI:10.1002/aorn.12579.

[6] 中国医师协会急诊医师分会,中国人民解放军急救医学专业委员会,中国医师协会急诊医师分会急诊外科专业委员会.止血带的急诊应用专家共识[J].中华急诊医学杂志,2020,29(6):773-779. DOI:10.3760/cma.j.issn.1671-0282.2020.06.006.

[7] National Clinical Guideline Centre UK. Fractures (Complex): Assessment and Management[M]. London: National Institute for Health and Care Excellence (UK),2016.

[8] American College of Surgeons. 10th Edition of the Advanced Trauma Life Support (ATLS)[J]. 2018. Student Course.

[9] Yamamoto R, Udagawa K, Nishida Y, et al. Damage control orthopedics and decreased in-hospital mortality: A nationwide study[J]. Injury, 2019,50(12):2240-2246. DOI:10.1016/j.injury.2019.09.028.

[10] Fan H, Fei R, Guo C, et al. Effects of emergency treatment mode of damage-control orthopedics in pelvic fracture complicated with multiple fractures[J]. Am J Transl Res, 2021,13(6):6817-6826.

[11] Cimbanassi S, O'Toole R, Maegele M, et al. Orthopedic injuries in patients with multiple injuries: Results of the 11th trauma update international consensus conference Milan, December 11,2017[J]. J Trauma Acute Care Surg,2020,88(2):e53-e76. DOI:10.1097/TA.0000000000002407.

[12] Monazzam S, Goodell PB, Salcedo ES, et al. When are CT angiograms indicated for patients with lower extremity fractures? A review of 275 extremities[J]. J Trauma Acute Care Surg,2017,82(1):133-137. DOI:10.1097/TA.0000000000001258.

[13] Weger K, Hammer P, McKinley T, et al. Incidence and clinical impact of lower extremity vascular injuries in the setting of whole body computed tomography for trauma[J]. Emerg Radiol,2021,28(2):265-272. DOI:10.1007/s10140-020-01847-5.

[14] Dreizin D, Smith EB, Champ K, et al. Roles of trauma CT and CTA in salvaging the threatened or mangled extremity[J]. Radiographics, 2022,42(2):E50-E67. DOI:10.1148/rg.210092.

[15] Gregory RT, Gould RJ, Peclet M, et al. The mangled extremity syndrome(M.E.S.): A severity grading system for multisystem injury of the extremity[J]. J Trauma,1985,25(12):1147-1150.

[16] Georgescu AV, Battiston B. Mangled upper extremity: Our strategy of reconstruction and clinical results[J]. Injury, 2021,52(12):3588-3604. DOI:10.1016/j.injury.2021.04.004.

[17] Gustilo RB, Mendoza RM, Williams DN. Problems in the management of type III (severe) open fractures: A new classification of type III open fractures[J]. J Trauma,1984,24(8):742-746. DOI:10.1097/00005373-198408000-00009.

[18] 顾立强,朱庆棠,戚剑.开放性骨折改良 Gustilo 分型与保肢策略[J].中华显微外科杂志,2017,40(1):13-15. DOI:10.3760/cma.j.issn.1001-2036.2017.01.005.

[19] Nayar SK, Alcock H, Edwards DS. Primary amputation versus limb salvage in upper limb major trauma: A systematic review[J]. Eur J Orthop Surg Traumatol,2022,32(3):395-403. DOI:10.1007/s00590-021-03008-x.

[20] Potter C, Bosse MJ. American academy of orthopaedic surgeons clinical practice guideline summary for limb salvage or early amputation[J]. J Am Acad Orthop Surg,2021,29(13):e628-e634. DOI:10.5435/JAAOS-D-20-00188.

[21] Hoogervorst LA, Hart MJ, Simpson PM, et al. Outcomes of severe lower limb injury with Mangled Extremity Severity Score ≥7[J]. Bone Joint J,2021,103-B(4):769-774. DOI:10.1302/0301-620X.103B4.BJJ-2020-1647.R1.

[22] Schechtman DW, Walters TJ, Kauvar DS. Utility of the mangled extremity severity score in predicting amputation in military lower extremity arterial injury[J]. Ann Vasc Surg,2021,70:95-100. DOI:10.

1016/j.avsg.2020.08.095.

[23] Loh B, Lim JA, Seah M, et al. Perioperative management of open fractures in the lower limb[J]. J Perioper Pract,2022,32(5):100-107. DOI:10.1177/17504589211012150.

[24] Wordsworth M, Lawton G, Nathwani D, et al. Improving the care of patients with severe open fractures of the tibia: The effect of the introduction of Major Trauma Networks and national guidelines[J]. Bone Joint J,2016,98-B(3):420-424. DOI:10.1302/0301-620X.98B3.35818.

[25] Gupta A, Parikh S, Rajasekaran RB, et al. Comparing the performance of different open injury scores in predicting salvage and amputation in type IIIB open tibia fractures[J]. Int Orthop,2020,44(9):1797-1804. DOI:10.1007/s00264-020-04538-5.

[26] National Clinical Guideline Centre (UK). Major trauma: Service delivery[J]. London: National Institute for Health and Care Excellence (NICE),2016.

[27] 朱庆棠,顾立强.严重肢体创伤综合保肢原则——一个中心 两个阶段 四个重点 八项技术[J].中华显微外科杂志,2021,44(4):361-363. DOI:10.3760/cma.j.cn441206-20210726-00181.

[28] Suriyakumar S, Saluja SS, Ramanujam M, et al. Management of grade 3c compound injury of lower limb with floating knee-salvage versus amputation(case series)[J]. J Orthop Case Rep,2021,11(2):119-127. DOI:10.13107/jocr.2021.v11.i02.2052.

[29] Liang NL, Alarcon LH, Jeyabalan G, et al. Contemporary outcomes of civilian lower extremity arterial trauma[J]. J Vasc Surg,2016,64(3):731-736. DOI:10.1016/j.jvs.2016.04.052.

[30] Hansen EL, Pedersen L, Lindberg-Larsen M. Acute compartment syndrome[J]. Ugeskr Laeger,2021,183(27):V11200817.

[31] Osborn CPM, Schmidt AH. Management of acute compartment syndrome[J]. J Am Acad Orthop Surg,2020,28(3):e108-e114. DOI:10.5435/JAAOS-D-19-00270.

[32] Prodromidis AD, Charalambous CP. The 6-hour rule for surgical debridement of open tibial fractures: A systematic review and meta-analysis of infection and nonunion rates[J]. J Orthop Trauma,2016,30(7):397-402. DOI:10.1097/BOT.0000000000000573.

[33] Romagnoli AN, Morrison JJ, DuBose JJ, et al. Dichotomy in fasciotomy: Practice patterns among trauma/acute care surgeons with performing fasciotomy with peripheral arterial repair[J]. Am Surg,2020,86(8):1010-1014. DOI:10.1177/0003134820942138.

[34] Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: Retrospective and prospective analyses[J]. J Bone Joint Surg Am,1976,58(4):453-458.

[35] Warrender WJ, Lucasti CJ, Chapman TR, et al. Antibiotic management and operative debridement in open fractures of the hand and upper extremity: A systematic review[J]. Hand Clin,2018,34(1):9-16. DOI:10.1016/j.hcl.2017.09.001.

[36] Li J, Wang Q, Lu Y, et al. Relationship between time to surgical debridement and the incidence of infection in patients with open tibial fractures[J]. Orthop Surg,2020,12(2):524-532. DOI:10.1111/os.12653.

[37] You DZ, Schneider PS. Surgical timing for open fractures: Middle of the night or the light of day, which fractures, what time?[J]. OTA Int, 2020,3(1):e067. DOI:10.1097/OI9.0000000000000067.

[38] Chang Y, Bhandari M, Zhu KL, et al. Antibiotic prophylaxis in the management of open fractures: A systematic survey of current practice and recommendations[J]. JBJS Rev,2019,7(2):e1. DOI:10.2106/JBJS.RVW.17.00197.

[39] Doshi P, Gopalan H, Sprague S, et al. Incidence of infection following internal fixation of open and closed tibia fractures in India (INFINITI): A multi-centre observational cohort study[J]. BMC Musculoskelet Disord,2017,18(1):156. DOI:10.1186/s12891-017-1506-4.

[40] Al-Hourani K, Stoddart M, Khan U, et al. Orthoplastic reconstruction of type IIIB open tibial fractures retaining debrided devitalized cortical segments: The Bristol experience 2014 to 2018[J]. Bone Joint J,2019,101-B(8):1002-1008. DOI:10.1302/0301-620X.101B8.BJJ-2018-1526.R2.

[41] Fowler T, Whitehouse M, Riddick A, et al. A retrospective comparative cohort study comparing temporary internal fixation to external fixation at the first stage debridement in the treatment of type iiib open diaphyseal tibial fractures[J]. J Orthop Trauma,2019,33(3):125-130. DOI:10.1097/BOT.0000000000001362.

[42] Giotikas D, Tarazi N, Spalding L, et al. Results of the induced membrane technique in the management of traumatic bone loss in the lower limb: A cohort study[J]. J Orthop Trauma,2019,33(3):131-136. DOI:10.1097/BOT.0000000000001384.

[43] Tetsworth K, Paley D, Sen C, et al. Bone transport versus acute shortening for the management of infected tibial non-unions with bone defects[J]. Injury,2017,48(10):2276-2284. DOI:10.1016/j.injury.2017.07.018.

[44] Aktuglu K, Erol K, Vahabi A. Ilizarov bone transport and treatment of critical-sized tibial bone defects: A narrative review[J]. J Orthop Traumatol,2019,20(1):22. DOI:10.1186/s10195-019-0527-1.

[45] 王祥,李青松,梁伟,等.一期骨短缩吻合血管结合二期骨延长治疗小腿 Gustilo Ⅲ C 型骨折八例[J].中华显微外科杂志,2021,44(6):663-667. DOI:10.3760/cma.j.cn441206-20210422-00109.

[46] 郭浩,汤俊君,张军,等.一次性皮肤拉拢装置治疗难闭性皮肤软组织缺损的疗效分析[J].中国修复重建外科杂志,2022,36(6):760-765. DOI:10.7507/1002-1892.202201068.

[47] Bhandari M, Jeray KJ, Petrisor BA, et al. A trial of wound irrigation in the initial management of open fracture wounds[J]. N Engl J Med, 2015,373(27):2629-2641. DOI:10.1056/NEJMoa1508502.

[48] Sprague S, Petrisor B, Jeray K, et al. Wound irrigation does not affect health-related quality of life after open fractures: Results of a randomized controlled trial[J]. Bone Joint J,2018,100-B(1):88-94. DOI:10.1302/0301-620X.100B1.BJJ-2017-0955.R1.

[49] 邓佩军,杨建涛,秦本刚,等.影响四肢主要动脉损伤修复术后早期肢体血运的术前危险因素研究[J].中华创伤骨科杂志,2022,24(3):247-252. DOI:10.3760/cma.j.cn115530-20210616-00287.

[50] Sharrock AE, Tai N, Perkins Z, et al. Management and outcome of

597 wartime penetrating lower extremity arterial injuries from an international military cohort[J]. J Vasc Surg,2019,70(1):224-232. DOI:10.1016/j.jvs.2018.11.024.

[51] Xu Y, Xu W, Wang A, et al. Diagnosis and treatment of traumatic vascular injury of limbs in military and emergency medicine: A systematic review[J]. Medicine (Baltimore),2019,98(18):e15406. DOI:10.1097/MD.0000000000015406.

[52] 唐举玉.特殊形式穿支皮瓣系列教程(一)——血流桥接穿支皮瓣[J]. 中华显微外科杂志,2022,45(4):476-480. DOI:10.3760/cma.j.cn441206-20220629-00134.

[53] Laverty RB, Treffalls RN, Kauvar DS. Systematic review of temporary intravascular shunt use in military and civilian extremity trauma[J]. J Trauma Acute Care Surg,2022,92(1):232-238. DOI:10.1097/TA.0000000000003399.

[54] Polcz JE, White JM, Ronaldi AE, et al. Temporary intravascular shunt use improves early limb salvage after extremity vascular injury [J]. J Vasc Surg,2021,73(4):1304-1313. DOI:10.1016/j.jvs.2020.08.137.

[55] Tung L, Leonard J, Lawless RA, et al. Temporary intravascular shunts after civilian arterial injury: A prospective multicenter Eastern Association for the Surgery of Trauma study[J]. Injury,2021,52(5):1204-1209. DOI:10.1016/j.injury.2020.12.035.

[56] 黄喜军,王东,郑灿镔,等.小血管临时转流的实验研究与临床应用[J].中华显微外科杂志,2014,37(3):258-262. DOI:10.3760/cma.j.issn.1001-2036.2014.03.016.

[57] Kauvar DS, Staudt AM, Arthurs ZM, et al. Early fasciotomy and limb salvage and complications in military lower extremity vascular injury[J]. J Surg Res, 2021,260:409-418. DOI:10.1016/j.jss.2020.10.017.

[58] Ratnayake A, Worlton TJ. Role of prophylactic fasciotomy in contemporary vascular trauma practices[J]. Injury,2022,53(2):811-812. DOI:10.1016/j.injury.2021.07.015.

[59] Moran BJ, Quintana MT, Scalea TM, et al. Two urgency categories, same outcome: No difference after "therapeutic" vs. "prophylactic" fasciotomy[J]. Am Surg,2021:31348211031860. DOI:10.1177/0003134 8211031860.

[60] Kluckner M, Gratl A, Gruber L, et al. Predictors for the need for fasciotomy after arterial vascular trauma of the lower extremity[J]. Injury, 2021,52(8):2160-2165. DOI:10.1016/j.injury.2021.05.044.

[61] Ye Z, Zhao S, Zeng C, et al. Study on the relationship between the timing of conversion from external fixation to internal fixation and infection in the treatment of open fractures of extremities[J]. J Orthop Surg Res,2021,16(1):662. DOI:10.1186/s13018-021-02814-7.

[62] Kisitu DK, O'Hara NN, Slobogean GP, et al. Unreamed intramedullary nailing versus external fixation for the treatment of open tibial shaft fractures in uganda: A randomized clinical trial[J]. J Orthop Trauma, 2022,36(9):349-357. DOI:10.1097/BOT.0000000000002362.

[63] Albright PD, Ali SH, Jackson H, et al. Delays to surgery and coronal malalignment are associated with reoperation after open tibia fractures in tanzania[J]. Clin Orthop Relat Res,2020,478(8):1825-1835. DOI:10.1097/CORR.0000000000001279.

[64] Campbell S, Dhyani J, Greenberg P, et al. Outcomes in patients with late debridement of open long bone fractures of the lower extremities in penetrating trauma: A retrospective review of the National Trauma Data Bank[J]. Eur J Orthop Surg Traumatol,2020,30(6):1075-1081. DOI:10.1007/s00590-020-02672-9.

[65] Galal S. Minimally invasive plate osteosynthesis has equal safety to reamed intramedullary nails in treating Gustilo-Anderson type I, II and III-A open tibial shaft fractures[J]. Injury,2018,49(4):866-870. DOI:10.1016/j.injury.2018.03.008.

[66] 张伯松,顾航宇,孙志坚,等.加速康复外科理念下开放性骨折诊疗规范专家共识[J].中华骨与关节外科杂志,2020,13(2):89-96. DOI:10.3969/j.issn.2095-9958.2020.02.01.

[67] 中华医学会骨科学分会创伤骨科学组,中华医学会骨科学分会外固定与肢体重建学组,中国医师协会创伤外科医师分会创伤感染专业委员会,等.中国开放性骨折诊断与治疗指南(2019 版)[J].中华创伤骨科杂志,2019,21(11):921-928. DOI:10.3760/cma.j.issn.1671-7600.2019.11.001.

[68] Haonga BT, Liu M, Albright P, et al. Intramedullary nailing versus external fixation in the treatment of open tibial fractures in tanzania: Results of a randomized clinical trial[J]. J Bone Joint Surg Am,2020,102(10):896-905. DOI:10.2106/JBJS.19.00563.

[69] Al-Hourani K, Donovan R, Stoddart MT, et al. Definitive fixation outcomes of open tibial shaft fractures: Systematic review and network meta-analysis[J]. J Orthop Trauma,2021,35(11):561-569. DOI:10.1097/BOT.0000000000002090.

[70] Yokoyama K, Itoman M, Uchino M, et al. Immediate versus delayed intramedullary nailing for open fractures of the tibial shaft: A multivariate analysis of factors affecting deep infection and fracture healing[J]. Indian J Orthop,2008,42(4):410-419. DOI:10.4103/0019-5413.43385.

[71] 徐永清,范新宇.再议肢体严重创伤的修复和重建[J].中华创伤骨科杂志,2018,20(8):645-647. DOI:10.3760/cma.j.issn.1671-7600.2018.08.001.

[72] Major Extremity Trauma Research Consortium(METRC). Modern external ring fixation versus internal fixation for treatment of severe open tibial fractures: A randomized clinical trial(FIXIT study)[J]. J Bone Joint Surg Am,2022,104(12):1061-1067. DOI:10.2106/JBJS.21.01126.

[73] Meselhy MA, Singer MS, Halawa AM, et al. Gradual fibular transfer by ilizarov external fixator in post-traumatic and post-infection large tibial bone defects[J]. Arch Orthop Trauma Surg,2018,138(5):653-660. DOI:10.1007/s00402-018-2895-z.

[74] Huang Q, Xu Y, Lu Y, et al. Acute shortening and re-lengthening versus antibiotic calcium sulfate-loaded bone transport for the management of large segmental tibial defects after trauma[J]. J Orthop Surg Res,2022,17(1):219. DOI:10.1186/s13018-022-03109-1.

[75] Ael-S S, Badawy E, Hasan M, et al. Management of post-traumatic bone defects of the tibia using vascularised fibular graft combined with Ilizarov external fixator[J]. Injury,2016,47(4):969-975. DOI:10.

1016/j.injury.2016.01.033.

[76] Huang Q, Ren C, Li M, et al. Antibiotic calcium sulfate-loaded hybrid transport versus traditional Ilizarov bone transport in the treatment of large tibial defects after trauma[J]. J Orthop Surg Res,2021,16(1):568. DOI:10.1186/s13018-021-02723-9.

[77] 赵广跃.严重开放性骨折治疗的新理念——骨整形[J].中华显微外科杂志,2019,42(6):521-523. DOI:10.3760/cma.j.issn.1001-2036.2019.06.001.

[78] Kang Y, Wu Y, Ma Y, et al. "Primary free-flap tibial open fracture reconstruction with the Masquelet technique" and internal fixation [J]. Injury,2020,51(12):2970-2974. DOI:10.1016/j.injury.2020.10.039.

[79] Cherubino M, Valdatta L, Tos P, et al. Role of negative pressure therapy as damage control in soft tissue reconstruction for open tibial fractures[J]. J Reconstr Microsurg,2017,33(S1):S8-S13. DOI:10.1055/s-0037-1606542.

[80] Choudry U, Moran S, Karacor Z. Soft-tissue coverage and outcome of Gustilo grade IIIB midshaft tibia fractures: A 15-year experience [J]. Plast Reconstr Surg,2008,122(2):479-485. DOI:10.1097/PRS.0b013e31817d60e0.

[81] Godina M. Early microsurgical reconstruction of complex trauma of the extremities[J]. Plast Reconstr Surg,1986,78(3):285-292. DOI:10.1097/00006534-198609000-00001.

[82] Shammas RL, Mundy LR, Truong T, et al. Identifying predictors of time to soft-tissue reconstruction following open tibia fractures[J]. Plast Reconstr Surg,2018,142(6):1620-1628. DOI:10.1097/PRS.0000000000005007.

[83] Rymer B, Dimovska E, Chou D, et al. A representative assessment of the management of open fractures of the lower limb within UK orthoplastic centres: A two-centre audit of compliance with national standards [J]. Injury,2017,48(10):2266-2269. DOI:10.1016/j.injury.2017.07.012.

[84] Costa ML, Achten J, Knight R, et al. Negative-pressure wound therapy compared with standard dressings following surgical treatment of major trauma to the lower limb: The WHIST RCT[J]. Health Technol Assess,2020,24(38):1-86. DOI:10.3310/hta24380.

[85] Costa ML, Achten J, Parsons NR, et al. Five-year outcomes for patients sustaining severe fractures of the lower limb: Mid-term results from the Wound management for Open Lower Limb Fracture (WOLLF) trial[J]. Bone Joint J,2022,104-B(5):633-639. DOI:10.1302/0301-620X.104B5.BJJ-2021-1568.R2.

[86] Norman G, Shi C, Goh EL, et al. Negative pressure wound therapy for surgical wounds healing by primary closure[J]. Cochrane Database Syst Rev,2022,4(4):CD009261. DOI:10.1002/14651858.CD009261.pub7.

[87] Costa ML, Achten J, Knight R, et al. Effect of incisional negative pressure wound therapy vs standard wound dressing on deep surgical site infection after surgery for lower limb fractures associated with major trauma: The whist randomized clinical trial[J]. JAMA,2020,323(6):519-526. DOI:10.1001/jama.2020.0059.

[88] Myatt A, Saleeb H, Robertson G, et al. Management of Gustilo-Anderson IIIB open tibial fractures in adults-a systematic review[J]. Br Med Bull,2021,139(1):48-58. DOI:10.1093/bmb/ldab013.

[89] Young K, Aquilina A, Chesser T, et al. Open tibial fractures in major trauma centres: A national prospective cohort study of current practice[J]. Injury,2019,50(2):497-502. DOI:10.1016/j.injury.2018.10.028.

[90] Yang Z, Xu C, Zhu YG, et al. Radical treatment of severe open fractures of extremities by orthoplastic surgery: A 10-year retrospective study[J]. J Orthop Surg Res,2021,16(1):340. DOI:10.1186/s13018-021-02479-2.

[91] Olson JJ, Anand K, Esposito JG, et al. Complications and soft-tissue coverage after complete articular, open tibial plafond fractures[J]. J Orthop Trauma,2021,35(10):e371-e376. DOI:10.1097/BOT.0000000000002074.

[92] Kang Y, Wu Y, Ma Y, et al. "Primary free-flap tibial open fracture reconstruction with the Masquelet technique" and internal fixation [J]. Injury,2020,51(12):2970-2974. DOI:10.1016/j.injury.2020.10.039.

[93] Philandrianos C, Moullot P, Gay AM, et al. Soft tissue coverage in distal lower extremity open fractures: Comparison of free anterolateral thigh and free latissimus dorsi flaps[J]. J Reconstr Microsurg,2018,34(2):121-129. DOI:10.1055/s-0037-1607323.

[94] 戚建武,陈邵,孙斌鸿,等.游离背阔肌肌皮瓣联合人工真皮及刃厚皮治疗下肢脱套伤的临床效果[J].中华烧伤与创面修复杂志,2022,38(4):347-353. DOI:10.3760/cma.j.cn501120-20210421-00145.

[95] 付记乐,罗桦杰,詹晓欢,等. Flow-through 背阔肌肌皮瓣修复儿童四肢创面[J].中华显微外科杂志,2020,43(3):261-265. DOI:10.3760/cma.j.cn441206-20200207-00046.

[96] McMahon HA, Stranix JT, Lee ZH, et al. Management of Gustilo type IIIC injuries in the lower extremity[J]. Clin Plast Surg,2021,48(2):267-276. DOI:10.1016/j.cps.2020.12.006.

[97] 裴蛟森,韩岩,李杨,等.游离皮瓣桥式移植修复严重皮肤软组织缺损[J].中华整形外科杂志,2022,38(7):780-786. DOI:10.3760/cma.j.cn114453-20210601-00241.

[98] 叶吉忠,柴益民,陆男吉,等.带隐神经营养血管交腿筋膜皮瓣修复小腿创伤性骨外露创面[J].中华显微外科杂志,2007,30(4):297-299. DOI:10.3760/cma.j.issn.1001-2036.2007.04.024.

[99] 张宇轩,许亚军,崔毅,等.三种不同形式的小腿内侧岛状皮瓣临床应用分析[J].中华显微外科杂志,2020,43(1):5-9. DOI:10.3760/cma.j.issn.1001-2036.2020.01.003.

(收稿日期:2022-10-10)

· Expert Consensus ·

Expert consensus on early treatment of severe open limb injury

ZHU Qingtang[1], LI Wenjun[2], ZHU Lei[3], ZHENG Xianyou[4], WU Panfeng[5], ZHONG Gang[6], HUANG Xijun[1], DENG Peijun[1]

[1]The First Affiliated Hospital of Sun Yat-sen University, Guangzhou 510080, China; [2]Beijing Jishuitan Hospital, Beijing 100035, China; [3]Qilu Hospital of Shandong University, Jinan 250012, China; [4]The Sixth People's Hospital Affiliated to Shanghai Jiaotong University, Shanghai 201103, China; [5]Xiangya Hospital, Central South University, Changsha 410013, China; [6]West China Hospital of Sichuan University, Chengdu 610044, China

Corresponding author: ZHU Qingtang, Email: zhuqingt@mail.sysu.edu.cn, Tel: +86 20 8761 8242

DOI: 10.3760/cma.j.cn441206- 20221010-00207

Severe open limb injury is commonly seen in high-energy injuries, featuring variety of damages to tissues and structures. With a severe injury, it may affect a survival of the limb or even be a threat to life and pose a severe impact on limb function. Great challenges are faced in this kind of injury, whether in the injury assessment, treatment decision-making or implementation of treatment. There are high requirements on the time limit for first-aid treatment, in skill of medical team and comprehensive treatment ability of a hospital. It is necessary for a hospital to have strong abilities in injury judgment and monitoring, injury control, life support, tissue repair and reconstruction, and complication prevention[1]. Patients with severe open limb injury are usually sent to the closest hospital for accident and emergency (A&E) treatment. However, many patients may often have missed out the best time for treatment as they could be referred to number of hospitals before arrival of the hospital that has the required medical expertise to handle the injury. More seriously, due to various reasons, some patients have failed to receive proper treatment hence missed out the opportunity of limb salvage or left with serious limb disability[2].

To address the requirement for early treatment of severe open limb injury, this consensus puts forward basic principles and suggestions in injury assessment for first aid, decision-making for treatment, reconstruction of limb blood circulation, bone and joint fixation, wound surface treatment, etc. in order to enable the medical practitioners to handle with actual diagnosis and treatment process, and to provide professional advices in grading, classification and timely standardised treatment.

This consensus focuses on early treatment of severe open limb injury. It does not cover the closed injuries, multiple injuries with limb trauma, complete severed limb and secondary repair and functional reconstruction of a limb.

I Definition of severe open limb injury

A severe open limb injury refers to the injuries in an upper or lower limb caused by high-energy impacts. It features open wounds, damage of multiple tissues, and the severe injuries that may endanger to life or affect the survival of the affected limb[1]. To diagnose a severe open limb injury, three conditions listed next must be all met: (1)Caused by high energy impact; (2)Open wound with multiple tissue damages; (3)Immediate threat of life or survival of limb. For example, following are the severe open limb injuries caused by high-energy impacts: a large area of skin degloving, skin and soft tissue defects, main vessel injury of extremity, Gustilo IIIB/IIIC fractures, etc.

II Evaluation of severe open limb injury

1.On-site assessment and pre-hospital first-aid measures

(1)Systemic assessment. On the injury site, it must quickly check whether there exists a life-threatening injury. First, check the vital signs, consciousness and pupils. Then check the patient following the alphabetical order of CRASHPLAN: Cardiac, Respiratory, Abdomen, Spine, Head, Pelvis, Limb, Artery and Nerve, and provide the patient with basic life support (BLS)[3].

(2)Assessment of injured limbs. Whether there exist injuries that endanger a survival of the limbs should be assessed on the site. Following aspects should be focused on: blood circulation of the injured extremities (skin colour and temperature, arterial pulsation, capillary backfilling reaction), nerve function(motion and sensation), wound(bleeding, contamination, tissue defect, etc.), and stability of bone and joint[4].

(3)First-aid on site. for an active bleeding, the wound should be pressurised and banded to stop bleeding. For a large blood vessel injury with a bleeding that is difficult to control, a tourniquet can be used whenever it is necessary. The pressure and time of applying the tourniquet should be strictly controlled, and the time of per tourniquet should not exceed 2 hours[5-6]. For limbs with joint dislocation, a reduction should be attempted in the very first place, except for the heavily contaminated open fractures on the accident site. If it allows, a contaminated wound should be briefly cleaned on the accident site, have it covered with sterilised dressing and fix the injured limb with simple splints. The fixation of a fracture should exceed the proximal and distal joints to the fracture site, while attentions should be paid to avoid compression of blood vessels and nerves[7]. Otherwise, if above measures are not allowed on site, take any available materials and measures to stop bleeding, cover the wound and fix the fracture.

2.In-hospital assessment

(1)Systemic and local assessment. After on-site emergency treatment, patients with severe open limb injury should be reassessed for systemic and wound conditions after arrival at a hospital. The in-hospital assessment and first-aid should be carried out according to the principles and methods of Advanced Trauma Life Support (ATLS)[8] and Damage Control Orthopaedics(DCO)[9-11].

(2)Medical imaging assessment. It mainly involves vascular imaging and bone and joint imaging. For a suspected arterial injury of extremity, vascular ultrasound or computed tomography angiography(CTA) scans should be taken immediately while the vital signs are stable. A digital subtraction angiography(DSA) can be taken if necessary[12-13]. Imaging examination of bone and joint of the extremity also includes X-rays of the fracture site and the proximal and distal joints to it. For the intra-articular and periarticular fractures, a CT scan with three-dimensional reconstruction should be performed. However, it must be pointed out that the treatment for life-saving or limb ischemia must not be delayed for taking an imaging examination[14].

(3)Severity assessment. The mangled extremity severity score(MESS)[15](Table 1) can be used to assess the severity of injured extremity.

(4)Psychosocial assessment. Patients with severe open limb injury together with their families often have psychological stress disorder due to a severity of the injury and the difficulties in estimation of the costs for medical treatment and expectation of the prognosis. Assessment of psychological factors to and medical counselling with the patient and family should be conducted. The ability of patient to access resources from social supports to finance an active treatment should be taken into an estimation and consideration, together with the ethnic, religious and other factors, hence to put forward a plan for an appropriate medical treatment.

Tab.1　Mangled Extremity Severity Score

Variables	Grading	Score(Point)
Skeletal/soft-tissue injury	Low energy	1
	Medium energy	2
	High energy	3
	Very high energy	4
Shock	Normal blood pressure	1
	Transient hypotension	2
	Persistent hypotension	3
Limb ischemia (Double the scores for ischemia over 6 hours)	Normal(Pulse and perfusion normal)	0
	Mild(Pulse reduced but perfusion normal)	1
	Moderate(Pulseless)	2
	Severe(Cool, paralysed)	3
Age (Years)	<30	0
	30-50	1
	>50	2

3.Intra-operation assessment

After the completion of advanced life support and initial assessment of severity of limb injury, patient with severe open limb injury shall be sent to the operating room for further debridement. Injured limbs should be re-assessed during debridement[16]. ①For wound and skin: Pay attention to the extent, depth, contamination and skin vitality of the wound, special attention must be paid to find out if there is a skin degloving or sneaking peeling, and skin defects. ②For muscles and tendons: Judge the muscle vitality according to the 4C indicators, namely Colour, Contractibility, Consistency and Capacity of blood. Check the integrity of tendons, especially an avulsion at the junction of tendon and muscle belly or at the proximal end of a tendon that retracts into the muscle belly. ③For vessels and nerves: Check the continuity

of blood vessels and nerves, whether there exists a vascular contusion, thrombosis, or vascular break or rupture; Whether there exists contused or ruptured nerves. ④For bone and joint: Check the stability of bone and joint, whether there exists a fracture and(or) joint dislocation, the extents of fracture comminution, size of fractured blocks and degree of dissociation and contamination. For a patient with open fracture, the assessment should be conducted according to Gustilo-Anderson Classification[17] or Modified Gustilo-Anderson Classification[18] after debridement.

III Decision-making for treatment of severe open limb injury

A severe open limb injury endangers the survival of a limb, therefore whether the limb could be salvaged must be firstly determined at the primary treatment[19-20]. For those with MESS ≤7 points, limb salvage should be performed as far as possible; For those with MESS >7 points, whether a limb could be salvaged, or not, depends on a comprehensive assessment of the injury, treatment conditions, patient's willingness, etc.[2,21-22].

The indications for limb amputation in severe open limb injury must be strictly controlled. In principle, it requires consultations with specialists in orthopaedic microsurgery[23-24] to confirm that a limb salvage is not appropriate or impossible, before a limb amputation surgery[25]; If the receiving hospital is not able to facilitate the limb salvage, the patient should be transferred in time, to a hospital that is able to facilitate the limb salvage, unless a transfer can not be made due to the patient's own reasons[26]. In the selection of limb salvage treatment for severe open limb injury[27], following conditions must be met: ① The vital signs are stable, functions of major organs are not significantly impaired, and the patient is able to tolerate the limb salvage treatment; ②The injured limb is able to survive after the reconstruction of blood circulation; ③After a repair and reconstruction surgery, some recoveries of limb function are expected; ④The patient and his or her family have a strong desire to save the limb, with guaranteed sufficient financial and other required supports, be full compliance and cooperative with all the procedures in treatment.

Whether the limb should be salvaged for an individual patient, it is necessary to consider the situations of both doctors and patient to make an individualised determination[28].

IV Principles of early treatment for severe open limb injury

1. Life is the first. To save the life is the most important task in early treatment of severe open limb injury. Assessment and emergency treatment can be carried out according to the principles and methods specified in the ATLS and DCO.

2. Prevent a vicious circle of "ischemia-necrosis-infection". A severe open limb injury faces very high risks of tissue ischemia, necrosis and infection. The 3 said risks may influence upon each other and enter with a vicious circle. With a severe injury of a limb, either with a redistribution of the volume of systemic circulating blood, or a local vascular damage, or an occurrence of compartment syndrome, they all lead to an insufficient tissue perfusion, hence ischemia, hypoxia and necrosis; The direct effect of a high energy impact may cause a tissue necrosis, trigger a local or even systemic inflammatory reaction, and consequently aggravate tissue ischemia and hypoxia; When an open injury occurs, skin barrier is destroyed and opens to invasion by pathogenic microorganisms, which easily causes an infection. Tissue ischemia weakens the body ability to remove microorganisms and it makes the necrotic tissue become a hotbed for growth of microorganisms, so that both factors together accelerate the occurrence and development of infection. Therefore, timely measures must be taken to restore/improve tissue blood perfusion, thoroughly remove necrotic tissues and close the wound in the early treatment of severe open limb injury.

3. Establish blood circulation first. A limb salvage is under the premise of save-life. The key for a limb salvage is to gain a blood circulation. A main artery injury that affects blood supply to the limbs must be repaired first, and the accompanying veins must also be repaired[29]; In case of a compartment syndrome, a fasciotomy must be performed in time for fully decompression[30-31]. An ischemic time must be controlled within 6-8 hours[32-33].

4.Stabilise bone and joint. For a patient with fracture and joint dislocation, stable fixation should be applied after the best possible restoration of the length and weight transmission line of the affected limb; For Gustilo III C type fractures with large soft tissue defects, external fixator is usually the first choice. Limited internal fixation can be carefully implemented when soft tissue conditions allow to do so. A best possible reduction and

fixation should performed for intra-articular fractures. For those with vascular repair or large skin and soft tissue defects, it is recommended to apply external fixators in order to keep a limb stability. Stable bone and joint structures protect blood vessels and allow further wound repair in a later stage.

5. Repair of nerves, muscles and tendons. Nerves, muscles and tendons should be repaired as soon as possible in stage I surgery, after a throughout debridement in a severe limb injury. It may be difficult to carry out an one-off complete debridement for a badly contaminated trauma so as it is often difficult to achieve an stage I repair. Therefore, under such circumstance, it is suggested that the wound should be repaired in the stage Ⅱ surgery, after a thorough debridement, to achieve an effective coverage of the wound.

6. Timely cover the wound. Timely wound coverage is an important measure to prevent infection and to minimise complications. A temporary wound coverage or a definitive repair surgery would be accordingly determined, depending on the general and wound conditions of a pa tient.

Ⅴ Debridement

1. General principles. It cannot be overemphasised that a debridement is an important measure in the management of severe open limb injury and is the basis for reconstruction and in recovery of limb functions[16,34]. Following principles are recommended for implementation in debridement: ①As far as the general condition of a patient allows, wound must be debrided in a timely manner. In particular, a debridement should be carried out as soon as possible when encounters a serious wound contamination(i.e. marine and freshwater products, agriculture, sewage, etc.)[35-36], an early symptoms of compartment syndrome and with a vascular injury. ②Arrange an experienced surgeon to carry out a debridement will safeguard to a more careful and thorough debridement hence to improve the outcome of a patient[2,37]. ③Follow aseptic and minimally invasive principles. ④Remove all foreign bodies and inactivated tissues thoroughly from a wound, stop bleeding completely and clean the wound as best as possible. ⑤Close a wound as early as possible based on a thorough debridement. For injuries in special environments such as seawater, agricultural fields or sewages, and for special types of injuries such as human and animal bite and thermal pressure, it is recommended that only stage I debridement should be performed, then re-exploration of soft tissues and bones should be carried out within 24-48 hours to remove all secondary necrotic and (or) infected tissues. Sometimes repeated and multiple debridement are required.

2. Debridement: necessary preoperative preparations. They include: ①Preparation of instruments, such as sterile surgical kit, saline, soapy water, complex iodine solution and tourniquet, etc.; ②Administration of antibiotics prophylactically[38-39], and sufficient dosage of effective antibiotics should be administered according to the Guidelines for the Prophylactic Administration of Antibiotics; ③Injection of tetanus antitoxin, give 1 500 U for a mild injury and 3 000 U for a severe injury; ④Maintain a good anaesthesia; ⑤A tourniquet is recommended for a bloodless surgical field in debridement.

3. Debridement: steps and methods. (1)After a wound has been covered with sterile dressing, the affected limb shall be cleaned with soapy water and routine disinfection procedures. (2)Remove all foreign bodies, contaminated soft tissue, especially the inactivated tissues. (3)If necessary, incision should be extended until a clean and well-bleeding tissues is seen. (4)Debridement should be carried out thoroughly, in the manner of "carpet debridement", from surface to depth and from outside to inside. Remove all foreign bodies, contaminants and inactivated skin, fat, muscle and bone to avoid cross-contamination of wounds. ①For skin: the skin vitality can be judged according to bleeding at edges of skin. First, trim the edge of wound if necessary. Remove the avulsed skin with obvious extrusion and crushing without hesitation, in order to avoid further issues. For the avulsed skin with mild contusion and good blood supply to deep muscle tissue and periosteum, skin replantation can be performed by making multiple small incisions on the replanted skin for drainage and the incisions should be made parallel to the motion axis of a joint. ②For muscles. Use the "4C principle" to determine the vitality of a muscle. Remove all inactivated muscles. ③For blood vessels. An obvious injured artery should be completely excised together with any arterial segment with a suspected injury, in order to avoid the risk of thrombosis and dehiscence of anastomosis at later stage. Never keep a damaged wall of blood vessel in an attempt to make do with either a simple task of vascular repair or to worry about difficulties in end-to-end vessel anastomosis since

too much tissues have been removed, and as a consequence, to do so will lead to a failure in vascular repair. ④For nerves. Remove contaminated epineurium and trim the severed ends of a nerve. Try the best to perform a tension-free suture in repair of a nerve at the primary stage. If a primary stage nerve repair is impossible, the broken end of a nerve should be marked and leave it for the stage II surgery. ⑤For tendons. Remove contaminated surface tissue of a tendon and trim the tendon fibres to same length. In principle, a tendon should be repaired at the primary surgery if it is possible. However, if the primary stage repair is impossible, the broken end of a tendon should be marked and have it repaired at stage II. ⑥For bone and joint. The vitality of bone mass is judged according to the bleeding on bone surface. It is still controversial in how to handle the crushed bone masses. For a piece of bone mass with good soft tissue attachment and a blood supply to the fractured mass, it could be kept. However, if a piece of bone mass is absolutely freed, it can only be retained after thorough debridement together with a good soft tissue coverage[40-41]. Therapeutic techniques of Masquelet[42], limb shortening[43], bone transport[45] and skin stretching[45-46] require a long period of treatment cycles therefore it can only be applied after adequate discussions with the patient and his or her family. (5)For wound cleaning. Severe open limb wounds should be routinely cleaned after thorough debridement, in order to remove contaminants, tissue debris and haematoma, reduce bacterial load on the wound, thus reduce the risk of infection. Saline is recommended for wound irrigation and it must be used in sufficient quantities. For Gustilo type I, type II and type III open fractures, the amount of wound irrigation should be at 3 L, 6 L and 9 L[47], respectively. Pulsed flush could be considered for cleaning of fresh wounds[48], but it is not recommended for an old or a chronically infected wounds.

VI Reconstitution of blood circulation

1. Classification and methods for repair of vascular injury. Vascular injury often coexists with severe soft tissue injury in a severe open limb injury. The conditions of the soft tissue surrounding a damaged blood vessel greatly affect the choice of repair methods and consequently the outcomes. Different repair options should be considered according to the soft tissue coverage over an injured blood vessel[49].

Type I: There is healthy soft tissue coverage over an injured vessel. According to various pathological types, thrombectomy, resection and anastomosis of the damaged vessels or vascular grafting, and endovascular treatment can be selected[50-51]. Autogenous vein graft is the first choice for a limb arterial defect. An artificial blood vessel should be used with great cautions.

Type II: There is no soft tissue coverage over an injured vessel. A surgery of Flow-through flap transfer or vein transfer together with a muscle(skin) flap coverage should be performed.

Type III: There is an extensive damages in the area of vascular injury with unclear boundary or secondary severe necrosis and infection. Following vascular reconstruction techniques can be considered: transposition of blood vessels from the healthy side of uninjured limb by fostering the affected limb in situ and to reconstruct the blood vessels in the stage Ⅱ surgery. Alternatively, axial flaps with main arteries and veins are made into skin tubes for grafting and bridging across the areas of vascular injury[52].

2. Special techniques for establishing blood circulation. For patients with an expected ischemic time over 6 hours, a temporary vascular diversion technique should be employed to re-establish a blood supply to the distal limb[53-56]. Thereafter, debridement, exploration, fracture fixation and other surgical procedures can be safely carried out.

3. Management of compartment syndrome. Acute compartment syndrome may occur in a severe open limb injury. Once a patient is found with a compartment syndrome, a prompt and adequate fascia incision for decompression should be carried out[57-59]. Prophylactic fasciotomy should be performed as a routine measure in patients with warm ischemia exceeded 8 hours[60].

VII Management of bone and joint injuries

1.Principles of bone and joint reduction and fixation. The main goal of bone and joint reduction and fixation is to provide adequate mechanical stability and minimise complications. A specific treatment plan is dependdent on the general condition of a patient, type of fractures and soft tissue conditions. A primary internal fixation should be considered for an injury after thorough debridement and with good soft tissue coverage[61-62]. However, severe open limb injury is often accompanied with severe soft tissue damages, poor soft tissue coverage at the fracture site and even with an unstable general con-

dition. In such a case, a temporary external fixation is recommended for primary treatment, and attentions should be paid in restoring the weight transmission line of the affected limb and maintaining the integrity of articular surface[63].

2. Timing and methods of fracture fixation. Based on a stable general condition and a good soft tissue coverage at the fracture site after thorough debridement, a primary internal fixation can be performed within 6 to 8 hours after injury[64]. If a good soft tissue coverage of the wound can be achieved within 48 to 72 hours after injury, a primary internal fixation could be considered.

Selection of plates and screws or intramedullary nails according to the injury site[65-67]. ①Plate and screw fixation. It is suitable for an intra-articular and metaphysis fracture where the articular surface integrity and fracture alignment reduction are required. Multiple plates or cannulated screws are used to improve the stability of fracture fixation. Absorbable materials or memory alloys are also suitable for fracture fixation. During the surgery, attention should be paid to protect the blood supply to the ends of a fracture and large bone fragments. It is not recommended to directly discard the bone fragments with no blood supply. Reduction and fixation should only be carried out based on a thorough debridement and without contamination. Soft tissue coverage with good blood supply provides good supports and bone healing[40]. ②Intramedullary nail fixation. For a shaft fracture in lower extremity, intramedullary nail fixation should be cautiously applied[68]. Expansion of medullary cavity is not recommended[69]. The implantation process of intramedullary nailing must be performed with a great caution, as an incision through a site of infection or contamination may cause severe intramedullary infection, leading to serious consequences of limb amputation[70].

For those who are not suitable for primary fixation, a temporary external fixation should be given, and have it turned to an absolute fixation at the stage Ⅱ surgery. For patients with a stable general condition, such as there are neither systemic inflammation nor infection in the nail track, and with good soft tissue conditions, it is recommended to switch to an absolute internal fixation as soon as possible within 14 days after the initial surgery[71-72]. For patients with severe wound contamination, potential risk of infection, and failure to meet above requirements after 14 days, a terminal external fixator can be employed until the fracture is healed. Otherwise, re-debridement and vacuum drainage shall be taken and wait, until the conditions of soft tissues allow an absolute internal fixation.

3. Management of bone defects. Repair of bone defects includes free bone grafting, bone transport and transfer of bone flap with blood vessel[73-76]. A free bone graft is generally suitable for a bone defect less than 2 cm; microsurgical transfer of a bone flap with pedicled blood-vessel or with a combined tissue flap transfer can effectively solve the problems in both of massive bone defect and soft tissue coverage. A large bone defect can be filled with antibiotic bone cement, or the defected bone can be shortened and fixed according to the conditions of surrounding soft tissues. A definite reconstruction can be performed at the stage Ⅱ[45].

Ⅷ Wound coverage

1.Principles of wound coverage. In order to achieve an early wound coverage for severe open limb injury, it is recommended to have the patient referred to a medical establishment, such as an orthopaedic and microsurgical centre, where the specially qualified staff can not only deal with fractures but also repair or reconstruct defects of soft tissue[77-78].

2. Timing of wound coverage. ①A wound should be covered as early as possible in the primary surgery. Wound coverage can only be performed under following conditions: a stable blood circulation, thorough debridement and without a foreseen bone and soft tissue infection. ②Delay a wound closure if necessary. Under the circumstance of an injury involving other important organs and/or with haemodynamic instability, for the purpose of damage control, VSD can be applied for temporarily coverage of the wound[79]. Other wound coverage methods are applicable depending on the actual situation of a patient, however a definite wound coverage shall be achieved within 3 to 7 days[80-83]. Should a gas gangrene or an uncomplete haemostasis of wound be suspected, it must avoid the use of a VSD. In addition, repeated use of VSD is not recommended[84-87].

3. Methods of wound covering. For a severe open limb injury, an early wound closure can effectively reduce the infection rate and promote fracture healing[16,88-91]. Specific recommendations for soft tissue repair and reconstruction are as follow: ①If there is no obvious defect of soft tissue after debridement, a direct suture or tension

reduction suture can be performed. ②For severe open limb injury with definite blood supply, such as an avulsed skin with mild contusion and a good blood supply in deep muscle tissue and periosteum, the avulsed skin can be used for replantation. If there is a severe contusion in the avulsed skin and a necrosis of the avulsed skin is expected, such as an avulsed skin must be removed without hesitation until a reliable blood supply to the skin is seen. Free flap(s) can be employed to cover a wound with exposure of bone in an emergency or sub-emergency surgery[92-93]. With a large area defect of soft tissues, it is difficult to directly cover a wound with exposure of tendons or bones by a single flap. A muscular (cutaneous) flap can be used to repair a wound with exposure of tendons and bones, and the rest of muscular wound surfaces can be temporarily covered by dressing or by a skin graft[94]. ③Local flap pedicled with blood vessels for wound coverage is not recommended for a wound with severe soft tissue defects. ④For Gustilo III C type limb injury, a stage I vascular transfer should be performed to re-establish a blood supply to the affected limb. If a blood vessel a exposed in the wound, flap coverages by a free flap, a vascularised muscle flap or a Flow-through flap[52,95] should be performed in the stage I surgery. In terms of flap selection, anterolateral thigh flap, latissimus dorsi flap[93,96-97] and traditional medial calf flap[98-99] should be fully utilised.

Disclaimer This consensus is a technical reference and only for the peers and specialists in microsurgery, trauma and orthopaedics, reconstructive and reconstructive surgery and other specialties. It should neither be taken as an absolute standard nor serve as a legal basis or a legal effect. It can not be referred as a legal or regulatory basis in any medical dispute. The listed principles are flexible and the consensus is time-limited, as they will be updated when more advanced and well-studied evidences and theories are emerged in the future

Members of the expert consensus group(Listed in alphabetical order by surname in Chinese Pinyin)

CHEN Zhenbin(Union Hospital, Tongji Medical College, Huazhong University of Science and Technology), GU Liqiang(The First Affiliated Hospital, Sun Yat-sen University), HOU Chunlin (Shanghai Changzheng Hospital of Naval Medical University), HOU Jianxi(Zhengzhou Renji Hospital), LIU Xiaolin(The First Affiliated Hospital, Sun Yat-sen University), TANG Juyu(Xiangya Hospital, Central South University), WANG Huaqiao(Editorial Board, Chinese Journal of Microsurgery), WANG Xin(Ningbo No.6 Hospital), XU Yongqing(No. 920 Hospital of PLA Joint Support Force), YU Aixi(Zhongnan Hospital of Wuhan University), ZHANG Changqing (The Sixth People's Hospital Affiliated to Shanghai Jiaotong University), ZHAO Guangyue(Xijing Hospital Affiliated to Air Force Military Medical University), ZHENG Xiaoju(Hand and Foot Microsurgical Hospital, Xi'an Fengcheng Hospital)

Conflict of interest All authors declare no conflict of interests

References

[1] Bumbaširević M, Matić S, Palibrk T, et al. Mangled extremity-modern concepts in treatment[J]. Injury,2021,52(12):3555-3560. DOI:10.1016/j.injury.2021.03.028.

[2] Sharrock M. The mangled extremity: Assessment, decision making and outcomes[J]. Acta Orthop Belg,2021,87(4):755-760. DOI:10.52628/87.4.22.

[3] The National Institute for Health and Care Excellence (NICE). Major Trauma: Assessment and Initial Management[J]. 2016.

[4] Shafiq B, Hacquebord J, Wright DJ, et al. Modern principles in the acute surgical management of open distal tibial fractures[J]. J Am Acad Orthop Surg,2021,29(11):e536-e547. DOI:10.5435/JAAOS-D-20-00502.

[5] Jensen J, Hicks RW, Labovitz J. Understanding and optimizing tourniquet use during extremity surgery[J]. AORN J,2019,109(2):171-182. DOI:10.1002/aorn.12579.

[6] Emergency Physicians College of Chinese Medical Doctor Association; Emergency Medicine Committee of Chinese People's Liberation Army; Emergency Surgery Subcommittee of Emergency Physicians College of Chinese Medical Doctor Association. Expert Consensus on Emergency Application of Tourniquet[J]. Chin J Emerg Med,2020,29(6):773-779. DOI:10.3760/cma.j.issn.1671-0282.2020.06.006.

[7] National Clinical Guideline Centre UK. Fractures (Complex): Assessment and Management[M]. London: National Institute for Health and Care Excellence(UK),2016.

[8] American College of Surgeons. 10th Edition of the Advanced Trauma Life Support(ATLS)[J]. 2018. Student Course.

[9] Yamamoto R, Udagawa K, Nishida Y, et al. Damage control orthopedics and decreased in-hospital mortality: A nationwide study[J]. Injury,2019,50(12):2240-2246. DOI:10.1016/j.injury.2019.09.028.

[10] Fan H, Fei R, Guo C, et al. Effects of emergency treatment mode of damage-control orthopedics in pelvic fracture complicated with multiple fractures[J]. Am J Transl Res,2021,13(6):6817-6826.

[11] Cimbanassi S, O'Toole R, Maegele M, et al. Orthopedic injuries in patients with multiple injuries: Results of the 11th trauma update international consensus conference Milan, December 11,2017[J]. J Trauma Acute Care Surg,2020,88(2):e53-e76. DOI:10.1097/TA.0000000000002407.

[12] Monazzam S, Goodell PB, Salcedo ES, et al. When are CT angiograms indicated for patients with lower extremity fractures? A review of 275 extremities[J]. J Trauma Acute Care Surg,2017,82(1):133-137. DOI:10.1097/TA.0000000000001258.

[13] Weger K, Hammer P, McKinley T, et al. Incidence and clinical impact of lower extremity vascular injuries in the setting of whole body computed tomography for trauma[J]. Emerg Radiol,2021,28(2):265-272. DOI:10.1007/s10140-020-01847-5.

[14] Dreizin D, Smith EB, Champ K, et al. Roles of trauma CT and CTA in salvaging the threatened or mangled extremity[J]. Radiographics, 2022,42(2):E50-E67. DOI:10.1148/rg.210092.

[15] Gregory RT, Gould RJ, Peclet M, et al. The mangled extremity syndrome(M.E.S.): A severity grading system for multisystem injury of the extremity[J]. J Trauma,1985,25(12):1147-1150.

[16] Georgescu AV, Battiston B. Mangled upper extremity: Our strategy of reconstruction and clinical results[J]. Injury,2021,52(12):3588-3604. DOI:10.1016/j.injury.2021.04.004.

[17] Gustilo RB, Mendoza RM, Williams DN. Problems in the management of type III (severe) open fractures: A new classification of type III open fractures[J]. J Trauma,1984,24(8):742-746. DOI:10.1097/00005373-198408000-00009.

[18] Gu LQ, Zhu QT, Qi J. Modified Gustilo classification and limb salvage strategy for open fractures[J]. Chin J Microsurg,2017,40(1):13-15. DOI:10.3760/cma.j.issn.1001-2036.2017.01.005.

[19] Nayar SK, Alcock H, Edwards DS. Primary amputation versus limb salvage in upper limb major trauma: A systematic review[J]. Eur J Orthop Surg Traumatol,2022,32(3):395-403. DOI:10.1007/s00590-021-03008-x.

[20] Potter C, Bosse MJ. American Academy of Orthopaedic Surgeons Clinical Practice Guideline Summary for Limb Salvage or Early Amputation[J]. J Am Acad Orthop Surg,2021,29(13):e628-e634. DOI:10.5435/JAAOS-D-20-00188.

[21] Hoogervorst LA, Hart MJ, Simpson PM, et al. Outcomes of severe lower limb injury with Mangled Extremity Severity Score ≥7[J]. Bone Joint J,2021,103-B(4):769-774. DOI:10.1302/0301-620X.103B4.BJJ-2020-1647.R1.

[22] Schechtman DW, Walters TJ, Kauvar DS. Utility of the mangled extremity severity score in predicting amputation in military lower extremity arterial injury[J]. Ann Vasc Surg,2021,70:95-100. DOI:10.1016/j.avsg.2020.08.095.

[23] Loh B, Lim JA, Seah M, et al. Perioperative management of open fractures in the lower limb[J]. J Perioper Pract,2022,32(5):100-107. DOI:10.1177/17504589211012150.

[24] Wordsworth M, Lawton G, Nathwani D, et al. Improving the care of patients with severe open fractures of the tibia: the effect of the introduction of Major Trauma Networks and national guidelines[J]. Bone Joint J,2016,98-B(3):420-424. DOI:10.1302/0301-620X.98B3.35818.

[25] Gupta A, Parikh S, Rajasekaran RB, et al. Comparing the performance of different open injury scores in predicting salvage and amputation in type IIIB open tibia fractures[J]. Int Orthop, 2020,44(9):1797-1804. DOI:10.1007/s00264-020-04538-5.

[26] National Clinical Guideline Centre (UK). Major trauma: Service delivery[J]. London: National Institute for Health and Care Excellence (NICE),2016.

[27] Zhu QT, Gu LQ. Principles for salvaging a severely injured extremity—One core, two stages, four key points, eight techniques[J]. Chin J Microsurg,2021,44(4):361-363. DOI:10.3760/cma.j.cn441206-20210726-00181.

[28] Suriyakumar S, Saluja SS, Ramanujam M, et al. Management of grade 3c compound injury of lower limb with floating knee-salvage versus amputation(case series)[J]. J Orthop Case Rep,2021,11(2):119-127. DOI:10.13107/jocr.2021.v11.i02.2052.

[29] Liang NL, Alarcon LH, Jeyabalan G, et al. Contemporary outcomes of civilian lower extremity arterial trauma[J]. J Vasc Surg,2016,64(3):731-736. DOI:10.1016/j.jvs.2016.04.052.

[30] Hansen EL, Pedersen L, Lindberg-Larsen M. Acute compartment syndrome[J]. Ugeskr Laeger,2021,183(27):V11200817.

[31] Osborn CPM, Schmidt AH. Management of acute compartment syndrome[J]. J Am Acad Orthop Surg,2020,28(3):e108-e114. DOI:10.5435/JAAOS-D-19-00270.

[32] Prodromidis AD, Charalambous CP. The 6-hour rule for surgical debridement of open tibial fractures: A systematic review and meta-analysis of infection and nonunion rates[J]. J Orthop Trauma,2016,30(7):397-402. DOI:10.1097/BOT.0000000000000573.

[33] Romagnoli AN, Morrison JJ, DuBose JJ, et al. Dichotomy in fasciotomy: Practice patterns among trauma/acute care surgeons with performing fasciotomy with peripheral arterial repair[J]. Am Surg,2020,86(8):1010-1014. DOI:10.1177/0003134820942138.

[34] Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: Retrospective and prospective analyses[J]. J Bone Joint Surg Am,1976,58(4):453-458.

[35] Warrender WJ, Lucasti CJ, Chapman TR, et al. Antibiotic management and operative debridement in open fractures of the hand and upper extremity: A systematic review[J]. Hand Clin,2018,34(1):9-16. DOI:10.1016/j.hcl.2017.09.001.

[36] Li J, Wang Q, Lu Y, et al. Relationship between time to surgical debridement and the incidence of infection in patients with open tibial fractures[J]. Orthop Surg,2020,12(2):524-532. DOI:10.1111/os.12653.

[37] You DZ, Schneider PS. Surgical timing for open fractures: Middle of the night or the light of day, which fractures, what time?[J]. OTA Int,2020,3(1):e067. DOI:10.1097/OI9.0000000000000067.

[38] Chang Y, Bhandari M, Zhu KL, et al. Antibiotic prophylaxis in the management of open fractures: A systematic survey of current practice and recommendations[J]. JBJS Rev,2019,7(2):e1. DOI:10.2106/JBJS.RVW.17.00197.

[39] Doshi P, Gopalan H, Sprague S, et al. Incidence of infection following internal fixation of open and closed tibia fractures in India (INFINITI): A multi-centre observational cohort study[J]. BMC Musculoskelet Disord,2017,18(1):156. DOI:10.1186/s12891-017-1506-4.

[40] Al-Hourani K, Stoddart M, Khan U, et al. Orthoplastic reconstruction of type IIIB open tibial fractures retaining debrided devitalized cortical segments: The Bristol experience 2014 to 2018[J]. Bone Joint J,2019,101-B(8):1002-1008. DOI:10.1302/0301-620X.101B8.BJJ-2018-1526.R2.

[41] Fowler T, Whitehouse M, Riddick A, et al. A retrospective comparative cohort study comparing temporary internal fixation to external fixation at the first stage debridement in the treatment of type iiib open diaphyseal tibial fractures[J]. J Orthop Trauma,2019,33(3):125-130. DOI:10.1097/BOT.0000000000001362.

[42] Giotikas D, Tarazi N, Spalding L, et al. Results of the induced membrane technique in the management of traumatic bone loss in the lower limb: A cohort study[J]. J Orthop Trauma,2019,33(3):131-136. DOI:10.1097/BOT.0000000000001384.

[43] Tetsworth K, Paley D, Sen C, et al. Bone transport versus acute shortening for the management of infected tibial non-unions with bone defects[J]. Injury,2017,48(10):2276-2284. DOI:10.1016/j.injury.2017.07.018.

[44] Aktuglu K, Erol K, Vahabi A. Ilizarov bone transport and treatment of critical-sized tibial bone defects: A narrative review[J]. J Orthop Traumatol,2019,20(1):22. DOI:10.1186/s10195-019-0527-1.

[45] Wang X, Li QS, Liang W, et al. Eight cases of Gustilo type ⅢC fracture treated by primary bone shortening and vascular anastomosis combined with secondary bone lengthening[J]. Chin J Microsurg, 2021,44(6):663-667. DOI:10.3760/cma.j.cn441206-20210422-00109.

[46] Guo H, Tang JJ, Zhang J, et al. Effectiveness analysis of disposable skin stretch closure in treatment of skin and soft tissue defects[J]. Chin J Repar Reconstr Surg,2022,36(6):760-765. DOI:10.7507/1002-1892.202201068.

[47] Bhandari M, Jeray KJ, Petrisor BA, et al. A trial of wound irrigation in the initial management of open fracture wounds[J]. N Engl J Med, 2015,373(27):2629-2641. DOI:10.1056/NEJMoa1508502.

[48] Sprague S, Petrisor B, Jeray K, et al. Wound irrigation does not affect health-related quality of life after open fractures: Results of a randomized controlled trial[J]. Bone Joint J,2018,100-B(1):88-94. DOI:10.1302/0301-620X.100B1.BJJ-2017-0955.R1.

[49] Deng PJ, Yang JT, Qin BG, et al. Preoperative risk factors for early extremity blood supply after repair of major arterial injury[J]. Chin J Orthop Trauma,2022,24(3):247-252. DOI:10.3760/cma.j.cn115530-20210616-00287.

[50] Sharrock AE, Tai N, Perkins Z, et al. Management and outcome of 597 wartime penetrating lower extremity arterial injuries from an international military cohort[J]. J Vasc Surg,2019,70(1):224-232. DOI:10.1016/j.jvs.2018.11.024.

[51] Xu Y, Xu W, Wang A, et al. Diagnosis and treatment of traumatic vascular injury of limbs in military and emergency medicine: A systematic review[J]. Medicine(Baltimore),2019,98(18):e15406. DOI:10.1097/MD.0000000000015406.

[52] Tang JY. Series course of special perforator flaps(I)—Flow-through perforator flaps[J]. Chin J Microsurg,2022,45(4):476-480. DOI:10.3760/cma.j.cn441206-20220629-00134.

[53] Laverty RB, Treffalls RN, Kauvar DS. Systematic review of temporary intravascular shunt use in military and civilian extremity trauma[J]. J Trauma Acute Care Surg,2022,92(1):232-238. DOI:10.1097/TA.0000000000003399.

[54] Polcz JE, White JM, Ronaldi AE, et al. Temporary intravascular shunt use improves early limb salvage after extremity vascular injury[J]. J Vasc Surg,2021,73(4):1304-1313. DOI:10.1016/j.jvs.2020.08.137.

[55] Tung L, Leonard J, Lawless RA, et al. Temporary intravascular shunts after civilian arterial injury: A prospective multicenter Eastern Association for the Surgery of Trauma study[J]. Injury,2021,52(5):1204-1209. DOI:10.1016/j.injury.2020.12.035.

[56] Huang XJ, Wang D, Zheng CB, et al. The experimental study and clinical application of temporary intravascular shunt on small blood vessels[J]. Chin J Microsurg,2014,37(3):258-262. DOI:10.3760/cma.j.issn.1001-2036.2014.03.016.

[57] Kauvar DS, Staudt AM, Arthurs ZM, et al. Early fasciotomy and limb salvage and complications in military lower extremity vascular injury[J]. J Surg Res,2021,260:409-418. DOI:10.1016/j.jss.2020.10.017.

[58] Ratnayake A, Worlton TJ. Role of prophylactic fasciotomy in contemporary vascular trauma practices[J]. Injury,2022,53(2):811-812. DOI:10.1016/j.injury.2021.07.015.

[59] Moran BJ, Quintana MT, Scalea TM, et al. Two urgency categories, same outcome: No difference after "therapeutic" vs. "prophylactic" fasciotomy[J]. Am Surg,2021:31348211031860. DOI:10.1177/00031348211031860.

[60] Kluckner M, Gratl A, Gruber L, et al. Predictors for the need for fasciotomy after arterial vascular trauma of the lower extremity[J]. Injury,2021,52(8):2160-2165. DOI:10.1016/j.injury.2021.05.044.

[61] Ye Z, Zhao S, Zeng C, et al. Study on the relationship between the timing of conversion from external fixation to internal fixation and infection in the treatment of open fractures of extremities[J]. J Orthop Surg Res,2021,16(1):662. DOI:10.1186/s13018-021-02814-7.

[62] Kisitu DK, O'Hara NN, Slobogean GP, et al. Unreamed intramedullary nailing versus external fixation for the treatment of open tibial shaft fractures in uganda: A randomized clinical trial[J]. J Orthop Trauma,2022,36(9):349-357. DOI:10.1097/BOT.0000000000002362.

[63] Albright PD, Ali SH, Jackson H, et al. Delays to surgery and coronal malalignment are associated with reoperation after open tibia fractures in tanzania[J]. Clin Orthop Relat Res,2020,478(8):1825-1835. DOI:10.1097/CORR.0000000000001279.

[64] Campbell S, Dhyani J, Greenberg P, et al. Outcomes in patients with late debridement of open long bone fractures of the lower extremities in penetrating trauma: A retrospective review of the National Trauma Data Bank[J]. Eur J Orthop Surg Traumatol,2020,30(6):1075-1081. DOI:10.1007/s00590-020-02672-9.

[65] Galal S. Minimally invasive plate osteosynthesis has equal safety to reamed intramedullary nails in treating Gustilo-Anderson type I, II and III-A open tibial shaft fractures[J]. Injury,2018,49(4):866-870. DOI:10.1016/j.injury.2018.03.008.

[66] Zhang BS, Gu HY, Sun ZJ, et al. Expert Consensus on Diagnosis and Treatment of Open Fracture Based on Enhanced Recovery after Surgery Concept[J]. Chin J Bone Joint Surg,2020,13(2):89-96. DOI:10.3969/j.issn.2095-9958.2020.02.01.

[67] Traumatic Orthopedics Group, Society of Orthopedics, Chinese Medical Association, Group of External Fixation and Limb Reconstruction, Society of Orthopedics, Chinese Medical Association, Professional Committee of Traumatic Infection, Society of Traumatic Surgeons, Association of Chinese Doctors, et al. Guidelines on diagnosis and treatment of open fractures in China(2019)[J]. Chin J Orthop Trauma,2019,21(11):921-928. DOI:10.3760/cma.j.issn.1671-7600.2019.11.001.

[68] Haonga BT, Liu M, Albright P, et al. Intramedullary nailing versus external fixation in the treatment of open tibial fractures in tanzania: Results of a randomized clinical trial[J]. J Bone Joint Surg Am,2020,102(10):896-905. DOI:10.2106/JBJS.19.00563.

[69] Al-Hourani K, Donovan R, Stoddart MT, et al. Definitive fixation outcomes of open tibial shaft fractures: Systematic review and network meta-analysis[J]. J Orthop Trauma,2021,35(11):561-569. DOI:10.1097/BOT.0000000000002090.

[70] Yokoyama K, Itoman M, Uchino M, et al. Immediate versus delayed intramedullary nailing for open fractures of the tibial shaft: A multivariate analysis of factors affecting deep infection and fracture healing[J]. Indian J Orthop,2008,42(4):410-419. DOI:10.4103/0019-5413.43385.

[71] Xu YQ, Fan XY. More words about repair and reconstruction of severe limb trauma[J]. Chin J Orthop Trauma,2018,20(8):645-647. DOI:10.3760/cma.j.issn.1671-7600.2018.08.001.

[72] Major Extremity Trauma Research Consortium (METRC). Modern external ring fixation versus internal fixation for treatment of severe

open tibial fractures: a randomized clinical trial(FIXIT study)[J]. J Bone Joint Surg Am,2022,104(12):1061-1067. DOI:10.2106/JBJS.21.01126.

[73] Meselhy MA, Singer MS, Halawa AM, et al. Gradual fibular transfer by ilizarov external fixator in post-traumatic and post-infection large tibial bone defects[J]. Arch Orthop Trauma Surg,2018,138(5):653-660. DOI:10.1007/s00402-018-2895-z.

[74] Huang Q, Xu Y, Lu Y, et al. Acute shortening and re-lengthening versus antibiotic calcium sulfate-loaded bone transport for the management of large segmental tibial defects after trauma[J]. J Orthop Surg Res,2022,17(1):219. DOI:10.1186/s13018-022-03109-1.

[75] Ael-S S, Badawy E, Hasan M, et al. Management of post-traumatic bone defects of the tibia using vascularised fibular graft combined with Ilizarov external fixator[J]. Injury,2016,47(4):969-975. DOI:10.1016/j.injury.2016.01.033.

[76] Huang Q, Ren C, Li M, et al. Antibiotic calcium sulfate-loaded hybrid transport versus traditional Ilizarov bone transport in the treatment of large tibial defects after trauma[J]. J Orthop Surg Res,2021,16(1):568. DOI:10.1186/s13018-021-02723-9.

[77] Zhao GY. A new concept for the treatment of severe open fractures: osteoplasty[J]. Chin J Microsurg,2019,42(6):521-523. DOI:10.3760/cma.j.issn.1001-2036.2019.06.001.

[78] Kang Y, Wu Y, Ma Y, et al. "Primary free-flap tibial open fracture reconstruction with the Masquelet technique" and internal fixation[J]. Injury,2020,51(12):2970-2974. DOI:10.1016/j.injury.2020.10.039.

[79] Cherubino M, Valdatta L, Tos P, et al. Role of negative pressure therapy as damage control in soft tissue reconstruction for open tibial fractures[J]. J Reconstr Microsurg,2017,33(S1):S8-S13. DOI:10.1055/s-0037-1606542.

[80] Choudry U, Moran S, Karacor Z. Soft-tissue coverage and outcome of gustilo grade IIIB midshaft tibia fractures: A 15-year experience [J]. Plast Reconstr Surg,2008,122(2):479-485. DOI:10.1097/PRS.0b013e31817d60e0.

[81] Godina M. Early microsurgical reconstruction of complex trauma of the extremities[J]. Plast Reconstr Surg,1986,78(3):285-292. DOI:10.1097/00006534-198609000-00001.

[82] Shammas RL, Mundy LR, Truong T, et al. Identifying predictors of time to soft-tissue reconstruction following open tibia fractures [J]. Plast Reconstr Surg,2018,142(6):1620-1628. DOI:10.1097/PRS.0000000000005007.

[83] Rymer B, Dimovska E, Chou D, et al. A representative assessment of the management of open fractures of the lower limb within UK orthoplastic centres: A two-centre audit of compliance with national standards[J]. Injury,2017,48(10):2266-2269. DOI:10.1016/j.injury.2017.07.012.

[84] Costa ML, Achten J, Knight R, et al. Negative-pressure wound therapy compared with standard dressings following surgical treatment of major trauma to the lower limb: The WHIST RCT[J]. Health Technol Assess,2020,24(38):1-86. DOI:10.3310/hta24380.

[85] Costa ML, Achten J, Parsons NR, et al. Five-year outcomes for patients sustaining severe fractures of the lower limb: Mid-term results from the Wound management for Open Lower Limb Fracture (WOLLF) trial[J]. Bone Joint J,2022,104-B(5):633-639. DOI:10.1302/0301-620X.104B5.BJJ-2021-1568.R2.

[86] Norman G, Shi C, Goh EL, et al. Negative pressure wound therapy for surgical wounds healing by primary closure[J]. Cochrane Database Syst Rev,2022,4(4):CD009261. DOI:10.1002/14651858.CD009261.pub7.

[87] Costa ML, Achten J, Knight R, et al. Effect of incisional negative pressure wound therapy vs standard wound dressing on deep surgical site infection after surgery for lower limb fractures associated with major trauma: The whist randomized clinical trial[J]. JAMA,2020,323(6):519-526. DOI:10.1001/jama.2020.0059.

[88] Myatt A, Saleeb H, Robertson G, et al. Management of Gustilo-Anderson IIIB open tibial fractures in adults-a systematic review[J]. Br Med Bull,2021,139(1):48-58. DOI:10.1093/bmb/ldab013.

[89] Young K, Aquilina A, Chesser T, et al. Open tibial fractures in major trauma centres: A national prospective cohort study of current practice[J]. Injury,2019,50(2):497-502. DOI:10.1016/j.injury.2018.10.028.

[90] Yang Z, Xu C, Zhu YG, et al. Radical treatment of severe open fractures of extremities by orthoplastic surgery: A 10-year retrospective study[J]. J Orthop Surg Res,2021,16(1):340. DOI:10.1186/s13018-021-02479-2.

[91] Olson JJ, Anand K, Esposito JG, et al. Complications and soft-tissue coverage after complete articular, open tibial plafond fractures[J]. J Orthop Trauma,2021,35(10):e371-e376. DOI:10.1097/BOT.0000000000002074.

[92] Kang Y, Wu Y, Ma Y, et al. "Primary free-flap tibial open fracture reconstruction with the Masquelet technique" and internal fixation[J]. Injury,2020,51(12):2970-2974. DOI:10.1016/j.injury.2020.10.039.

[93] Philandrianos C, Moullot P, Gay AM, et al. Soft tissue coverage in distal lower extremity open fractures: Comparison of free anterolateral thigh and free latissimus dorsi flaps[J]. J Reconstr Microsurg,2018,34(2):121-129. DOI:10.1055/s-0037-1607323.

[94] Qi JW, Chen S, Sun BH, et al. Clinical effects of free latissimus dorsi myocutaneous flap combined with artificial dermis and split-thickness skin graft in the treatment of degloving injury in lower extremity[J]. Chin J Burns Wounds,2022,38(4):347-353. DOI:10.3760/cma.j.cn501120-20210421-00145.

[95] Fu JL, Luo HJ, Zhan XH, et al. Application of flow-through latissimus dorsi musculocutaneous flap to repair the wounds in children's limb[J]. Chin J Microsurg,2020,43(3):261-265. DOI:10.3760/cma.j.cn441206-20200207-00046.

[96] McMahon HA, Stranix JT, Lee ZH, et al. Management of gustilo type IIIC injuries in the lower extremity[J]. Clin Plast Surg, 2021,48(2):267-276. DOI:10.1016/j.cps.2020.12.006.

[97] Pei JM, Han Y, Li Y, et al. The applications of cross-bridge free flap for reconstructions of severe soft tissue defects[J]. Chin J Plast Surg,2022,38(7):780-786. DOI:10.3760/cma.j.cn114453-20210601-00241.

[98] Ye JZ, Chai YM, Lu NJ, et al. Repair of traumatic bone exposure wound of lower leg with saphenous neurovascular interconnecting ham-fascia flap[J]. Chin J Microsurg,2007,30(4):297-299. DOI:10.3760/cma.j.issn.1001-2036.2007.04.024.

[99] Zhang YX, Xu YJ, Cui Y, et al. Clinical application of 3 types of the medial shank island flaps[J]. Chin J Microsurg,2020,43(1):5-9. DOI:10.3760/cma.j.issn.1001-2036.2020.01.003.

(Received date:2022-10-10)