RQ: Is there a clear preference regarding the choice of scoring systems in open injuries?

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Section 1: Background

High-energy trauma to the extremities — particularly Gustilo-Anderson type IIIB open tibial fractures — represents one of the most consequential clinical scenarios in orthopaedic surgery. The decision whether to attempt limb salvage or proceed with primary amputation carries profound medical, functional, economic, social, and medicolegal implications. Failed salvage leads to secondary amputations, extended hospitalisation, multiple operations, high infection rates, and functional outcomes often inferior to timely primary amputation.

Multiple injury severity scoring systems have been developed to standardise this decision. These include the Mangled Extremity Severity Score (MESS, 1990), Limb Salvage Index (LSI), Predictive Salvage Index (PSI), NISSSA score, Hannover Fracture Scale-97 (HFS-97), OTA Open Fracture Classification (OTA-OFC, 2010), Ganga Hospital Open Injury Severity Score (GHOISS, 1994/2006), and the novel Vetrivel Trauma Score (VTS, 2020). Each aims to provide objective, reproducible criteria for amputation decisions. Each approach the scoring problem differently: MESS, LSI, and PSI were derived from vascular trauma cohorts and weight ischaemia heavily; GHOISS systematically scores tissue-specific damage across skin, bone, and musculotendinous structures; VTS uniquely incorporates biochemical markers of rhabdomyolysis (creatine kinase, LDH, SpO2); and OTA-OFC provides a categorical anatomical classification rather than a summative score.

Critical limitations persist. Early scores — MESS, LSI, PSI — systematically underscore type-IIIB injuries without vascular compromise because ischaemia, their most heavily weighted component, is absent. In vascular trauma cohorts (where ischaemia is present), LSI and PSI paradoxically outperform MESS (Lee et al., 2022). The landmark LEAP study (Swiontkowski et al., 2002) demonstrated prospectively that no existing scoring system validated well across its 527-patient multicentre cohort, and that soft tissue injury severity — not ischaemia — drove actual amputation decisions. GHOISS addresses type-IIIB injuries by separately scoring covering tissues, skeletal structures, and functional tissues, and incorporating comorbid factors. Its use has been extended to adult LMIC settings (Uganda, Rwanda), to the paediatric population (Venkatadass et al., 2017, Ganga Hospital — where an elevated threshold of ≥17 applies), and independently validated in non-Ganga institutions. Whether MESS retains utility in upper extremity trauma (Slauterbeck 1994 versus Fochtmann 2016 — conflicting results) and whether novel biochemical scoring adds meaningfully beyond existing systems remain open questions.

Section 2: Data Extraction Table

S.No	Author, Year, Country	Study Design	Sample Size	Population (Inclusion/Exclusion)	Groups / Scores Compared	Key Results
1	Ebanezer E, Berin Jaba J 2023, India	Prospective observational	35 limbs 32 patients 28M:4F Mean age 30 yrs	Incl: High-energy leg injuries; Gustilo IIIB (severe muscle/nerve/bone) & IIIC; severe distal tibial injuries Excl: Prior treatment; non-ambulatory pre-injury; head injury; burns; spinal cord injury	PSI vs LSI vs MESS vs NISSSA vs HFS-97 vs GHOISS vs Gustilo-Anderson Outcome: Amputation vs salvage F/U: Until bone union	14 amputations (10 primary, 4 secondary); 21 salvages Sens/Spec/PPV/NPV: - PSI: 100/47.6/56/100% - LSI: 100/61.9/63.6/100% - MESS: 85.7/71.4/66.6/88.2% - NISSSA: 64.3/80.9/69.2/77.2% - HFS-97: 100/47.6/56/100% - GHOISS: 100/95/86/100% GHOISS only score achieving both high Sn and Sp
2	Rajasekaran S et al. 2006, India	Prospective validation (score development)	109 open tibial injuries (42 IIIA, 67 IIIB) 107M:2F Mean age 34.97 yrs	Incl: Open tibial injuries type IIIA/IIIB; within 24 hrs Excl: Prior debridement elsewhere; complete traumatic amputation; vascular injury requiring reconstruction; severe	GHS vs MESS vs Gustilo classification GHS groups: I(<5), II(6-10), III(11-15), IV(>=16) Amputation threshold:	7 amputations (5 primary, 2 secondary); 102 salvaged GHS vs MESS: Sn 98% vs 99%; Sp 100% vs 17%; PPV 100% vs 97.5%; NPV 70% vs 50% ROC AUC (IIIB): GHS 0.988 vs MESS 0.938 ICC: GHS 0.97 vs Gustilo 0.63

				ankle/foot injury	GHS>=14; MESS>=7 F/U: Mean 43 months	Outcomes by group: Days IP: I=10.1, II=23.4, III=61; Time to union: I=16, II=25, III=47wks; Deep infection: I=4.3%, II=13.7%, III=39.2%; Flap: I=4.3%, II=60.7%, III=100%
3	Slauterbeck JR et al. 1994, USA	Retrospective chart review	37 patients 43 upper extremity injuries	Incl: Open fractures of humerus, radius, ulna; mangled upper extremity proximal to hand where viability in question Excl: Not fully reported	MESS applied to upper extremity Threshold: MESS>=7 → amputation Gustilo grade vs MESS vs actual outcome F/U: Not reported	MESS>=7: 9 injuries → all 9 amputated MESS<7: 34 injuries → all 34 salvaged Sn 100% / Sp 100% / PPV 100% / NPV 100% First study demonstrating MESS utility in upper extremity
4	Bansal U et al. 2026, India	Prospective observational	307 patients Gustilo IIIB open tibial 85% male Mean age 28.67±9.28 yrs	Incl: Age 15-65; within 24 hrs; Gustilo IIIB open tibial fractures Excl: Type IIIC; near-total amputations; irreparable soft tissue; upper limb trauma	GHOISS vs MESS vs LSI Blinded independent scorer Amputation threshold: GHOISS>=15.5, MESS>=5.5, LSI>=3.5 (Youden Index) F/U: 6 months (6wk, 3mo, 6mo)	287 salvaged (93.5%); 20 amputated (14 primary 4.56%, 6 secondary 1.95%) AUC / Sn / Sp: - GHOISS: 0.997 / 100% / 95.8% - MESS: 0.958 / 100% / 82.7% - LSI: 0.953 / 100% / 83.8% All p<0.001; GHOISS superior Grey zone (15-16): all amputations at score>=16; none at <=15
5	Kwizera I et al. 2025, Rwanda	Prospective cohort study	111 patients open tibia IIIA & IIIB M:F 3.44:1 Mean age 34 yrs	Incl: Age>=18; open tibia IIIA/IIIB; debridement at study site Excl: Debridement elsewhere; lost to F/U; died during F/U; severe ankle/foot injury	GHOISS alone Groups: I(1-13), II(14-16), III(>=17) Amputation threshold: GHOISS>=14 F/U: 1 and 6 months	10 amputations (9.0%); mean stay 30.55 days; infection 54%; soft-tissue reconstruction 36.9% GHOISS (>=14): - Sn: 100% / Sp: 96.03% / PPV: 71.4% / NPV: 100% - ROC AUC: 0.98 Hospital stay: Group I 24.55d, II 84.81d, III 25.33d Covering tissue score strongly correlated with reconstruction need (Rs=0.7) GHOISS moderately correlated with infection (Rs=0.462)
6	Gupta A et al. 2020, India	Prospective study	219 patients 225 type IIIB open tibia M:F 11:1 Mean age ~42.6 yrs	Incl: Gustilo IIIB open tibia; within 24 hrs; all ages; all tibia sites Excl: Debridement elsewhere; complete traumatic amputations; vascular injury requiring reconstruction; isolated ankle/foot	MESS (>=7) vs LSI (>=6) vs OTA-OFC (>=10) vs GHS (grey zone 15-16; amputation >=17) Blinded independent scoring; treating team blinded to scores F/U: 1-2 years	193 salvaged (85.7%); 19 primary amputations (8.4%); 3 primary delayed (1.3%); 6 secondary (2.7%); 4 excluded (deaths) Sn/Sp/PPV/NPV at original thresholds: - MESS >=7: 29/95/47/90% - LSI >=6: 14/98/57/89% - OTA >=10: 36/92/40/91% - GHS >=14: 100/90/60/100% - GHS >=15: 89/97/81/98% - GHS >=17: 32/99/90/91% GHS superior for amputation; grey zone 14-17 captures most difficult cases MESS/LSI/OTA underscored amputees with intact vascularity
7	Hao J et al. 2016, USA	Retrospective observational cohort (Level IV)	512 patients 352M:160F Mean age 41.1±16.2 yrs (range 18-85) 19	Incl: Age>=18; open long bone fracture; operative treatment; min. 3 months F/U; single Level I trauma center Excl: Treatment at	OTA-OFC vs Gustilo-Anderson classification Outcomes: Amputation, infection, soft-tissue	Gustilo-Anderson: NO correlation with any outcome (amputation p=0.08; infection p=0.10) OTA-OFC: Significant differences for ALL outcomes:

			amputations (3.7%)	outside facility; insufficient medical records; F/U <3 months	coverage OTA-OFC scored retrospectively by 2 independent orthopaedic surgeons F/U: Min 3 months	- Amputation: OTA 10.9 vs salvage 6.37 ($p<0.001$) - Infection: OTA 8.1 vs no infection 6.3 ($p<0.01$) - Soft-tissue coverage: 9.6 vs 6.4 ($p<0.01$) ROC: OTA threshold>=10: Sn 78.9%, Sp 94.2%, PPV 34.1%, NPV 99.1% Skin injury = only independent predictor of amputation (OR 5.44, 95%CI 2.37-12.47, $p<0.001$) ICC between 2 observers: 0.556 ($p=0.011$) 21.1% with OTA>10 had fractures amenable to reconstruction (caution advised)
8	Sheean AJ et al. 2014, USA	Retrospective cohort study	153 patients 155 lower extremities Combat-related type III open tibia Median age 23 yrs (19-34) All military service members	Incl: Service members with combat-related type III open tibia fractures (2003-2007); treated definitively at US military medical center Excl: Incomplete records	MESS applied to combat-related type III open tibia fractures Threshold: MESS>=7 for amputation Comparison: Amputated vs salvaged extremities F/U: Variable (late amputations tracked to mean 15 months)	40 extremities amputated; 115 salvaged Median MESS: amputation 6 vs salvage 5 ($p=0.057$ — NOT significant) MESS >=7: Sn 35% / Sp 87.8% / PPV 50% / NPV 79.5% 30% amputees had vascular injury vs 11% salvaged ($p<0.0026$) 14 limbs with MESS>=7 successfully salvaged (50% false positive rate) 57.5% of amputated extremities had MESS 6-8 (overlap zone) 6 late amputations (mean 15 months): all had MESS 5-6 Conclusion: MESS should NOT be used in solitude for combat-related type III open tibia fractures
9	Swiontkowski MF et al. 2002, USA (LEAP Study)	Prospective multicentre cohort (8 Level I trauma centers)	527 patients analysed 408 salvaged 119 amputations (55 immediate, 64 delayed) Age 16-69 yrs	Incl: Age 16-69; Gustilo IIIB/IIIC tibial fractures; dysvascular limbs; IIIB ankle fractures; severe open midfoot/hindfoot injuries Excl: GCS<15 at 21 days; spinal cord deficit; prior amputation; 3rd degree burn; transferred >24h; bilateral study injuries	Analysis of actual decision-making factors (not score validation) All scoring system components collected and analysed Multivariate continuation-ratio logistic regression Surgeon survey (n=85) and multivariate analysis of 527 patients F/U: Part of LEAP study	Most important factors (multivariate): - Severe muscle injury: OR 8.74 (most important — deviance 86.1) - Absent plantar sensation: OR 5.26 - Severe deep vein injury: OR 5.72 - AO type A tibial Fx: OR 4.76 - Absent pulse: OR 2.02 - Private insurance (delayed amputation only): OR 2.48 Soft tissue injury explained most model variability Surgeon experience/fellowship did NOT influence decision No existing scoring system validated well in prospective LEAP cohort NOTE: This study analyses decision-driving factors, not score diagnostic accuracy
10	Okuku MD et al. 2025, Uganda	Prospective cohort study	49 fractures 48 adult patients (1 bilateral)	Incl: Gustilo type IIIA and B tibia fractures; within 24 hrs; any age or fracture location	GHOISS alone Scoring by blinded general surgery resident	43 salvaged (88%); 6 amputated (4 primary, 2 secondary) Optimal threshold: GHOISS=13 - AUC: 0.923 (95%CI 0.804-

			M:F 5:1 Mean age 37 yrs (SD 12.9)	Excl: Initial debridement elsewhere; traumatic amputations; significant vascular injury requiring repair	Decision by orthopaedic/general surgeon team Amputation threshold: Youden index (score=13) F/U: 14 days (early failure of limb salvage)	0.977) - Sensitivity: 83.3% - Specificity: 90.7% Mean GHOISS: salvage 8.8 (SD 2.6) vs amputation 14.8 (SD 3.4) 39/40 (97.5%) with GHOISS<13 salvaged 5/9 (55.6%) with GHOISS>=13 amputated Threshold 13 (lower than standard 14) attributed to absence of plastic surgeons No grey zone identified (attributed to small sample size) First application of GHOISS in Uganda/Africa
11	Madhuchandra P et al. 2015, India	Prospective observational (external validation)	40 open tibial injuries (11 IIIA, 29 IIIB) 38M:2F Mean age 38.15 yrs (range 16-70)	Incl: Age>17; open tibia IIIA/IIIB; within 24 hrs; presenting to tertiary referral centre Excl: Gustilo IIIC injuries; complete traumatic amputations; prior debridement elsewhere; age <17	GHOISS (threshold 14) vs MESS External validation of original Ganga Hospital study Groups: I(<5, n=3), II(6-10, n=20), III(11-15, n=16), IV(>15, n=1) ICC assessed by 6 independent observers F/U: Mean 24 months (range 10-36)	0 primary amputations; 1 secondary amputation (score 15, persistent infection/non-union) 39/40 limbs salvaged GHOISS threshold 14: Sn 100% / Sp 95% / Accuracy 95% MESS of amputated patient was 5 (below amputation threshold — confirms MESS unreliability) ICC: GHOISS 0.94 vs Gustilo-Anderson 0.72 Outcomes by group (comparable with original Ganga study): - Deep infection: Group I 0%, II 5%, III 50% - Flap requirement: Group I 0%, II 70%, III 100% - Mean time to union: Group I 18wks, II 20.1wks, III 28wks
12	Adegbehingbe OO et al. 2006, Nigeria	Prospective cohort (case series of primary amputees; no salvage comparison group)	66 primary amputations 52M:14F Mean age 28.6 yrs (range 4-71) From 3,812 trauma admissions (1.73%)	Incl: All trauma patients requiring primary amputation; OAUTHC Ile-Ife Nigeria; Jan 2000-Dec 2004 Excl: Known metabolic disorders; peripheral vascular disease	MESS applied to all primary amputation patients Threshold: MESS>=7 for amputation Clinical predictive factors identified by chi-square and t-test NOTE: No limb salvage comparison group — Sn/Sp cannot be calculated	All 66 patients had MESS>=7 (range 7-12, mean 9.4±1.3) MESS>=7: 100% of amputee cohort met threshold (case series only) Main clinical predictors: age, sex, limb ischaemia/gangrene, severe open fracture, shock, delay >6h 43.9% (29/66) had gangrene from traditional bone setter treatment Lower limb: 65.2%; upper limb: 34.8% 7 deaths; 6 from RTA LIMITATION: Design precludes Sn/Sp calculation; no salvage arm
13	Agel J et al. 2013, USA (Multicenter)	Prospective reliability study (NOT outcome prediction study)	136 raters (91 attending surgeons + 45 residents) 6 video cases of open fractures	Incl: Practicing orthopaedic surgeons/residents at 5 international sites IRB approved; videos de-identified; OTA classification reviewed before rating Purpose: Interrater reliability of OTA Open Fracture Classification	OTA Open Fracture Classification 5 categories: Skin (S), Muscle (M), Arterial (A), Bone loss (B), Contamination (C) Each with 3 severity levels (1=mild, 2=moderate, 3=severe) Comparison: Kappa vs published	Overall percent agreement: OTA-OFC 86% vs Gustilo-Anderson 60% (historical) Kappa by category: - Arterial: k=0.90 (near perfect) - Skin: k=0.69 (good) - Bone loss: k=0.65 (good) - Contamination: k=0.48 (moderate) - Muscle: k=0.40 (fair) Resident vs attending agreement similar for all categories Weakest: muscle injury and

					Gustilo-Anderson reliability data No clinical outcome data collected	contamination No summative scoring method exists (125 possible combinations)
14	Fochtmann A et al. 2016, Austria	Retrospective chart review (Level IV) 20-year period 1994-2014	54 patients 61 upper extremity injuries (IIIA n=30, IIIB n=15 IIIC n=9; sub/total amputation n=7) 39M:15F Median age 38 yrs (range 2-91)	Incl: Third degree open UE fractures or traumatic sub/total amputations; Level I trauma centre Vienna, Austria, 1994-2014 Excl: Not explicitly listed	MESS applied to upper extremity Threshold: MESS>=7 → amputation Comparison: Outcomes in MESS<7 vs MESS>=7 subgroups F/U: Median 11 months (range 1-124)	3 amputations (1 primary, 2 secondary) among 48 survivors; 6/54 (11%) died (all had MESS>=7, all polytrauma) MESS <7 (n=37): 37/37 (100%) limb salvage MESS >=7 (n=17): 9/17 (53%) limb salvage (47% amputated or died) Median MESS all patients: 5 (range 3-10); 17/54 (31%) had MESS>=7 Vascular injury 39%; neural injury 41% Definitive salvage rate 94% of survivors KEY FINDING: MESS >=7 does NOT predict amputation in upper extremity — 53% of survivors with MESS>=7 achieved definitive limb salvage Contrasts directly with Slauterbeck 1994 (100% prediction) — conflicts unresolved No functional outcome assessment — major limitation
15	Venkatadass K et al. 2017, India (Ganga Hospital)	Retrospective cohort (historical database) IRB approved	50 children 52 type IIIB open fractures (39 tibial, 13 femoral) Age 0-18 yrs 4 amputations 48 salvaged	Incl: Age 0-18 yrs; Open type IIIB lower limb injuries; direct presentation; Jan 2008-Mar 2015 Excl: Initial care given elsewhere; presentation >24h from injury	GHOISS vs MESS in paediatric population GHOISS threshold ROC-determined: 17 MESS threshold: 7 First study of GHOISS in children F/U: Not specified	4 amputations (2 primary, 2 secondary); 48/52 salvaged GHOISS threshold 17: Sn 75% / Sp 93.75% (ROC-optimal for children) MESS threshold 7: Sn only 25% (3 of 4 amputees had MESS 6 — below threshold) Mean GHOISS: amputation 17.25 vs salvage 11.74 (p<0.001) KEY FINDING: Children require higher GHOISS threshold (17 vs adult threshold 14) Reason: children compensate better for blood loss (hypotension a late sign) → MESS shock component underscores severity 3 patients with GHOISS>=17 had limbs salvaged — all <12 yrs, parents refused amputation All 4 amputees were males aged >15 yrs Limitation: Very small n (4 events), single centre, Ganga Hospital (institutional bias)
16	Lee CH et al. 2022, Taiwan	Retrospective cohort (10-year period) Cardiovascular surgery centre	53 cases of traumatic vascular injury in extremities (8 upper + 45 lower) 46M:7F	Incl: Traumatic vascular injury in extremities; all underwent vascular repair; Jan 2011-Dec 2020; tertiary referral centre Taiwan Excl: Criteria not explicitly listed	MESS vs LSI vs PSI Original and modified versions (time factor excluded) applied to all Amputation threshold (Youden):	11 amputations (all lower extremity, blunt trauma); no primary amputations Median MESS: amputation 8 vs salvage 6 (p=0.092 — NOT significant) Median LSI: amputation 7 vs salvage 4 (p=0.001 —

			Mean age 44.5 yrs (range 15-80) 11 amputations (20.8%)		MESS=8, LSI=6 (recommended 6), PSI=7 (recommended 8) Cox regression, Kaplan-Meier, ROC AUC analysis F/U: 30-day limb survival	significant) Median PSI: amputation 9 vs salvage 6 (p=0.004 — significant) AUC: MESS 0.64 vs LSI 0.84 vs PSI 0.79 Multivariable predictors of amputation: open fracture (HR 20.9, p=0.033), shock (HR 9.1, p=0.01), pRBC transfusion (HR 1.05, p=0.01) KEY FINDING: Even in vascular trauma (where ischaemia is present), MESS has poor discrimination (AUC 0.64, p=NS); LSI and PSI outperform MESS Ishaemic class correlated with outcomes (p=0.021) but ischaemia duration did not
17	Sengodan SVC et al. 2020, India	Prospective observational (novel score development)	52 patients Gustilo IIIB/IIIC lower limb (46 IIIB, 6 IIIC) 41M:11F Age 19-73 yrs 39 salvaged 13 amputated (12 primary, 1 secondary)	Incl: Gustilo IIIB and above lower limb; prospective; Dec 2017-Aug 2019; tertiary care centre Tamil Nadu India Excl: Gustilo I/II; IIIA fractures (good outcome); irreparable vascular injury; upper limb trauma	Novel VTS (Vetrivel Trauma Score) vs MESS vs Ganga score VTS: 12 non-laboratory clinical parameters + 3 biochemical markers (serum CK, LDH, SpO2) VTS range 6-55; Groups: I(5-16), II(17-28), III(29-38), IV(>=39 → amputation) ROC, binary logistic regression, ICC analysis F/U: In-hospital	All Group IV (VTS>=39): 13/13 amputated (100%) AUC: VTS 0.974±0.024 vs Ganga 0.964±0.025 vs MESS 0.960±0.028 Binary logistic regression: VTS (p<0.01) > Ganga (p=0.045) > MESS (p=0.048) > Gustilo (p=0.09) Kappa inter-observer agreement: 98.1% (range 96.4-99.8%) VTS also predicts wound infection, secondary procedures, hospital stay by group KEY FINDING: VTS marginally outperforms GHS (AUC 0.974 vs 0.964) by adding biochemical markers LIMITATION: Small n, single centre, includes IIIC (unlike GHS validation studies), score origin bias (authors developed the score), needs multicenter prospective validation

Section 3: Results Summary

Seventeen studies were included. Fifteen clinical outcome studies comprised approximately 2,240 injured extremities, and two supporting studies — a prospective reliability study (Agel et al., 2013, 136 raters) and a case series of amputees without a salvage comparison group (Adegbehingbe et al., 2006) — contributed contextual rather than diagnostic accuracy data. The clinical studies spanned India (six studies), USA (four), Uganda (one), Rwanda (one), Nigeria (one), Austria (one), and Taiwan (one). Study periods ranged from 1987-1990 to 2022-2026. Sample sizes ranged from 35 to 527 patients. The studies collectively evaluated MESS, LSI, PSI, NISSSA, HFS-97, GHOISS/GHS, OTA-OFC, VTS (Vetrivel Trauma Score), and combinations thereof.

The GHOISS/GHS consistently outperformed comparator scores in prospective studies of Gustilo type-IIIB open tibial fractures across adult populations. In the index study (Rajasekaran et al., 2006, n=109), GHS achieved 98% sensitivity and 100% specificity at threshold 14. Gupta et al. (2020, n=225) confirmed 100% sensitivity at GHS ≥14 versus 29%, 14%, and 36% for MESS, LSI, and OTA-OFC respectively. Bansal et al. (2026, n=307) demonstrated GHOISS AUC of 0.997. Ebanezer and Berin Jaba (2023, n=35) confirmed GHOISS as the only system achieving both high sensitivity and specificity simultaneously. External validation from an independent institution (Madhuchandra et al., 2015, n=40) replicated 100% sensitivity and 95% specificity at threshold 14.

GHOISS applicability extended to the paediatric population (Venkatadass et al., 2017, n=52 children at Ganga Hospital), where an elevated threshold of ≥17 was identified as optimal by ROC analysis (sensitivity 75%, specificity 93.75%), contrasting with the adult threshold of ≥14. MESS performed poorly in the paediatric cohort (sensitivity 25%), confirming that MESS components systematically underestimate injury severity in children. GHOISS performance in LMIC settings was validated in Rwanda (Kwizera et al., 2025, n=111, AUC 0.98) and Uganda (Okuku et al., 2025, n=49, AUC 0.923), where an even lower threshold of 13 was appropriate due to absent plastic surgical services.

MESS performance was assessed across four different clinical contexts with divergent results: (a) in the upper extremity, Slauterbeck et al. (1994) reported perfect discrimination (Sn/Sp 100%) in

43 injuries, while Fochtmann et al. (2016) found only 53% limb salvage rate among upper extremity patients with MESS ≥7 — demonstrating that MESS ≥7 does not reliably predict amputation in the mangled upper extremity; (b) in combat-related type III open tibial fractures (Sheean et al., 2014, n=155), MESS failed to discriminate amputated from salvaged extremities (p=0.057) with only 35% sensitivity; (c) even in vascular trauma — the domain for which MESS was originally designed — Lee et al. (2022, n=53) found MESS had an AUC of only 0.64 and was non-significant (p=0.092), while LSI (AUC 0.84) and PSI (AUC 0.79) performed significantly better. Only in Slauterbeck's original retrospective upper extremity series did MESS achieve perfect discrimination.

A novel scoring system, the Vetrivel Trauma Score (VTS, Sengodan et al., 2020, n=52), incorporating biochemical markers (serum CK, LDH, SpO2) in addition to clinical parameters, achieved AUC of 0.974 versus 0.964 for GHS and 0.960 for MESS in the same cohort. Inter-observer reliability was excellent (kappa 98.1%). All patients with VTS ≥39 underwent amputation (100%). While marginally superior to GHS, these findings require multicentre external validation before clinical adoption. The LEAP study (Swiontkowski et al., 2002, n=527) remained the most methodologically rigorous study and demonstrated that no existing scoring system validated well in a prospective multicentre cohort, reinforcing the primacy of soft tissue injury severity and plantar sensation as the true determinants of the amputation decision.

Section 4: Discussion

The most consistent finding across this seventeen-study evidence base is the systematic superiority of GHOISS/GHS over MESS, LSI, PSI, NISSSA, HFS-97, and OTA-OFC for predicting amputation in Gustilo type-IIIB open tibial fractures without vascular compromise, replicated across six independent prospective studies in adult populations from India, Rwanda, and Uganda spanning 900+ patients over 20 years.

The Fochtmann et al. (2016) data on upper extremity MESS is particularly important for resolving the apparent conflict with Slauterbeck (1994). Both studies are retrospective; Slauterbeck found 100% discrimination in 43 injuries, while Fochtmann found only 53% salvage among 17 patients with MESS ≥7. The difference may relate to case mix (Fochtmann included sub-total amputations and polytrauma), institutional approach (more aggressive salvage attempts at a major European centre), and the fundamental point that 20 years of improved microvascular surgical technique altered what is technically salvageable. The Fochtmann data, though level IV, is more contemporary and methodologically comparable. The combined weight of evidence from Fochtmann, Sheean, and Lee suggests that MESS as a standalone decision tool is unreliable across almost all clinical contexts: upper extremity, combat lower extremity, and even vascular trauma — the domain it was designed for.

The Lee et al. (2022) finding is the most counterintuitive and analytically valuable: even in a vascular trauma cohort (where ischaemia is present and MESS should perform best), MESS had an AUC of only 0.64 and was non-significant. LSI (AUC 0.84) and PSI (AUC 0.79) significantly outperformed MESS. This suggests that in vascular trauma, soft tissue involvement, contamination, and shock — captured more thoroughly by LSI and PSI — are more discriminating than the ischaemia weighting that defines MESS. Critically, open fracture (HR 20.9) was the strongest multivariate predictor of amputation — again pointing to soft tissue and skeletal injury as the driver, even in the presence of vascular injury. This finding aligns with the LEAP study's conclusion that muscle injury is the single most important determinant of actual clinical decision-making.

The Venkatadass et al. (2017) paediatric data extends GHOISS applicability to a clinically distinct population. The elevated threshold of ≥17 (versus the adult ≥14) has a clear mechanistic basis: children compensate haemodynamically longer, so hypotension is a late sign (suppressing the MESS shock component); all patients under 30 receive MESS age score of zero (eliminating the age component); and intact vascular status is common in crush injuries in children (reducing the MESS ischaemia component). All three MESS scoring components are therefore systematically suppressed in the paediatric setting, explaining the 25% sensitivity. The GHOISS addresses this by scoring tissue damage directly regardless of haemodynamics. Nonetheless, the small sample (4 events) and Ganga Hospital origin limit the strength of this conclusion; the recommended threshold of ≥17 for children is hypothesis-generating rather than practice-defining.

The VTS (Sengodan et al., 2020) introduces a genuinely novel element — biochemical markers of rhabdomyolysis — that no existing score incorporates. The rationale is sound: serum CK and LDH directly reflect ongoing muscle necrosis and provide evidence-based quantification of the tissue destruction that drives amputation decisions. The marginal AUC advantage over GHS (0.974 vs 0.964) is statistically small and potentially within the confidence interval, but the directional finding is consistent. VTS also demonstrated utility for predicting hospital stay, wound infection, and need for secondary procedures — a broader prognostic function beyond binary amputation prediction. The limitations are significant: n=52, single centre, score developed by the same authors who evaluated it, and inclusion of Gustilo IIIC patients (excluded by GHS validation studies). Multicentre external validation against GHS in a head-to-head prospective design is the necessary next step.

The expanding paediatric and LMIC data collectively argue that scoring thresholds are not universal — they must be calibrated to the patient population (adult vs child), anatomical site (lower vs upper extremity), injury mechanism (civilian vs combat), resource context (high-income with plastic surgery vs LMIC without), and vascular status (ischaemic vs non-ischaemic). This is a fundamental challenge to any single-threshold scoring system. The GHS architecture — with its grey zone, subscale scores, and co-morbidity weighting — provides more flexibility for contextual adaptation than any comparator score.

The key remaining evidence gaps are: prospective multicentre validation of VTS against GHS; a purpose-built upper extremity scoring system (MESS is inadequate, no alternative exists); prospective GHOISS data in the paediatric population from non-Ganga institutions; and patient-reported functional outcome data from all these populations. The LEAP study finding — that no existing score validated well in a rigorous prospective multicentre design — should be taken as a standing challenge to the field rather than a settled verdict on scores that have since been refined.

Section 5: Risk of Bias of Included Studies

Risk of bias was assessed using a modified Newcastle-Ottawa Scale adapted for diagnostic accuracy/observational studies across seven domains: patient selection, blinding/independence of scoring, independence of amputation decision, follow-up completeness, reporting quality, sample size, and generalisability. Overall ratings: LOW, MODERATE, or HIGH risk of bias. Studies 13 (reliability study) and 12 (amputee case series without salvage comparison) were rated on methodologically equivalent criteria for their study design.

Study	Patient Selection	Blinding of	Independence of Decision	Follow-up	Reporting Quality	Sample Size	Generalis-ability	OVERALL

		Scoring		Complete				
1. Ebanezer 2023 (India)	L	M	L	L	M	M	M	MOD
2. Rajasekaran 2006 (India)	L	L	L	L	L	L	M	LOW
3. Slauterbeck 1994 (USA)	M	H	H	H	M	H	H	HIGH
4. Bansal 2026 (India)	L	L	L	L	L	L	M	LOW
5. Kwizera 2025 (Rwanda)	L	M	M	L	M	M	L	MOD
6. Gupta 2020 (India)	L	L	L	L	L	L	M	LOW
7. Hao 2016 (USA)	M	M	H	M	M	L	M	MOD
8. Sheean 2014 (USA)	M	H	H	M	M	M	H	HIGH
9. Swiontkowski 2002 (USA)	L	L	L	L	L	L	L	LOW
10. Okuku 2025 (Uganda)	L	L	L	M	M	H	M	MOD
11. Madhuchandra 2015 (India)	L	M	M	L	M	H	M	MOD
12. Adegbehingbe 2006 (Nigeria)	H	H	H	M	M	M	M	HIGH
13. Agel 2013 (USA)	L	L	L	L	L	L	M	LOW
14. Fochtmann 2016 (Austria)	M	H	H	M	M	M	M	HIGH
15. Venkatadass 2017 (India)	M	H	H	M	M	H	M	HIGH
16. Lee 2022 (Taiwan)	M	M	H	M	L	M	M	MOD
17. Sengodan 2020 (India)	L	M	M	M	M	H	M	MOD

Key: L = Low risk (green) | M = Moderate risk (orange) | H = High risk (red) | OVERALL column (blue): LOW / MOD / HIGH overall risk of bias

No.	Study	Patient Selection	Blinding of Scoring	Independence of Decision	Follow-up Complete	Reporting Quality	Sample Size	Generalis-ability	OVERALL	Year
14	Ebanezer 2023 (India)	L	M	L	L	M	M	M	MOD	2023
9	Hao 2016 (USA)	M	M	H	M	M	L	M	MOD	2016
15	Kwizera 2025 (Rwanda)	L	M	M	L	M	M	L	MOD	2025
13	Lee 2022 (Taiwan)	M	M	H	M	L	M	M	MOD	2022
7	Madhuchandra 2015 (India)	L	M	M	L	M	H	M	MOD	2015
16	Okuku 2025 (Uganda)	L	L	L	M	M	H	M	MOD	2025
12	Sengodan 2020 (India)	L	M	M	M	M	H	M	MOD	2020
5	Agel 2013 (USA)	L	L	L	L	L	L	M	LOW	2013
17	Bansal 2026 (India)	L	L	L	L	L	L	M	LOW	2026

11	Gupta 2020 (India)	L	L	L	L	L	L	M	LOW	2020
4	Rajasekaran 2006 (India)	L	L	L	L	L	L	M	LOW	2006
2	Swiontkowski 2002 (USA)	L	L	L	L	L	L	L	LOW	2002
3	Adegbehingbe 2006 (Nigeria)	H	H	H	M	M	M	M	HIGH	2006
8	Fochtmann 2016 (Austria)	M	H	H	M	M	M	M	HIGH	2016
6	Sheean 2014 (USA)	M	H	H	M	M	M	H	HIGH	2014
1	Slauterbeck 1994 (USA)	M	H	H	H	M	H	H	HIGH	1994
10	Venkatadass 2017 (India)	M	H	H	M	M	H	M	HIGH	2017

Nine studies evaluated GHOISS/GHS directly:

1. **Rajasekaran 2006** — index development and validation study (GHS vs MESS, n=109)
2. **Ebanezer 2023** — head-to-head comparison of 6 scores including GHOISS (n=35)
3. **Bansal 2026** — GHOISS vs MESS vs LSI (n=307, largest prospective study)
4. **Kwizera 2025** — GHOISS alone in Rwanda (n=111, LMIC setting)
5. **Gupta 2020** — GHS vs MESS vs LSI vs OTA-OFC (n=225)
6. **Okuku 2025** — GHOISS alone in Uganda (n=49, LMIC setting, lower threshold of 13)
7. **Madhuchandra 2015** — external validation of GHS at non-Ganga institution (n=40)
8. **Venkatadass 2017** — GHS vs MESS in paediatric population (n=52, Ganga Hospital)
9. **Sengodan 2020** — VTS vs GHS vs MESS (n=52, novel score development)

All nine found GHOISS/GHS to be the best-performing or joint-best score. Three of the nine have a direct Ganga Hospital affiliation: Rajasekaran 2006 (index study, Ganga Hospital), Gupta 2020 (Rajasekaran as last author with Dheenadhayalan and Devendra as co-authors), and Venkatadass 2017 (Rajasekaran as last author, conducted at Ganga Hospital). The remaining six are institutionally independent: Ebanezer 2023, Bansal 2026, Kwizera 2025 (Rwanda), Okuku

2025 (Uganda), Madhuchandra 2015 (external validation at a non-Ganga institution), and Sengodan 2020 (Institute of Orthopaedics and Traumatology, Government Coimbatore Medical College Hospital — a government teaching hospital in Coimbatore, confirmed from the original publication; distinct from Ganga Hospital, which is a private specialty hospital in the same city). The institutional bias risk is therefore lower than initially stated, with six of nine validating studies conducted at independent institutions across four countries.

Section 6: Response / Recommendation

The Ganga Hospital Open Injury Severity Score (GHOISS/GHS) demonstrates consistently superior diagnostic accuracy and clinical utility for predicting amputation versus limb salvage in Gustilo type-IIIB open tibial fractures across multiple prospective studies in adult populations across diverse geographic settings. GHS is recommended as the preferred primary scoring tool for type-IIIA and IIIB open tibial fractures in adult patients. The amputation threshold must be interpreted in context: in the index study (Rajasekaran 2006), all patients scoring ≤14 were salvaged, scores 15–16 constituted the explicitly defined grey area of mixed outcomes, and scores ≥17 resulted in universal amputation. In Gupta et al. (2020), the zone of clinical uncertainty extended to include score 14, indicating the grey zone boundary is cohort-dependent. Scores within the grey area should be treated as a zone of individualised clinical judgement rather than a binary threshold. The optimal cut-off requires contextual calibration: ≥14 for standard adult settings, ≥13 in LMIC settings lacking plastic surgical services (Okuku et al., Uganda), and ≥17 in the paediatric population (Venkatadass et al., pending multicentre validation). MESS should not be used as a standalone decision-making tool in any of the following: (a) type-IIIB injuries without vascular compromise; (b) combat-related type III open tibia fractures; (c) the paediatric population; or (d) the upper extremity. Even in vascular trauma, LSI and PSI outperform MESS

(Lee et al., 2022). OTA-OFC offers substantially improved reliability over Gustilo-Anderson and better outcome prediction across diverse open fracture populations; a threshold of ≥10 identifies highest-risk cases. VTS (Sengodan et al., 2020) is a promising novel system incorporating biochemical markers, but requires multicentre external validation before clinical adoption. In LMIC settings, traditional bone setter gangrene, delayed presentation, and absence of specialist surgical services must be incorporated into the clinical decision alongside scoring, as these contextual factors may override score-based recommendations. Any scoring system should function as a structured decision aid supporting — not replacing — experienced multidisciplinary clinical judgement.

Section 7: Level / Strength of Evidence

Overall Level of Evidence: MODERATE

Justification: The evidence base comprises seventeen studies: fifteen clinical outcome studies (approximately 2,240 limbs) from India, USA, Uganda, Rwanda, Nigeria, Austria, and Taiwan, plus one OTA-OFC reliability study and one amputee case series. Among the fifteen clinical studies, nine are prospective and six retrospective. Three studies meet criteria for low risk of bias (Rajasekaran 2006, Bansal 2026, Gupta 2020); four are moderate risk; five are high risk (Slauterbeck 1994 retrospective, Sheean 2014 retrospective combat, Fochtmann 2016 retrospective, Venkatadass 2017 retrospective paediatric, Adegbehingbe 2006 case series). The LEAP multicentre prospective cohort (Swiontkowski 2002) remains the most rigorous study and found no existing score validated well in a prospective real-world design.

The addition of Fochtmann et al. (2016) and Lee et al. (2022) confirms that MESS is unreliable across multiple clinical contexts beyond type-IIIB tibial fractures, strengthening the evidence against MESS as a universal tool. Venkatadass et al. (2017) extends GHOISS applicability but from within Ganga Hospital, maintaining institutional bias risk. Sengodan et al. (2020) introduces biochemical markers into scoring but requires independent validation. **Key gaps remain:** absence of **long-term patient-reported functional outcomes**; no multicentre prospective head-to-head study of GHOISS versus VTS; **no purpose-built upper extremity scoring system among current systems**; **limited paediatric data** from independent institutions. **Evidence is sufficient to recommend GHOISS for adult type-IIIB tibial fractures, but upgrading to HIGH-quality evidence requires multicentre external validation from non-affiliated institutions**.

AI was used to populate tables 1 and 2, language check and script. Table 1 data was counterchecked manually but not table 2 due to limitations in time. Independent verification of tables is required to validate the findings. The authors have approved the final version and take full responsibility for the findings.

Abbrevaitions used Listed alphabetically:

AUC — Area Under the (Receiver Operating Characteristic) Curve — a single-number summary of a test's discriminative ability; 1.0 = perfect, 0.5 = no better than chance

CK — Creatine Kinase — a serum enzyme released by damaged muscle; elevated in rhabdomyolysis

GHS — Ganga Hospital Score (original name); same instrument as GHOISS

GHOISS — Ganga Hospital Open Injury Severity Score

HFS-97 — Hannover Fracture Scale 1997 — a German scoring system for mangled extremities, updated in 1997

kappa — Cohen's kappa — a statistical measure of interobserver agreement corrected for chance agreement; values: <0.20 poor, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 good, >0.80 near-perfect

LDH — Lactate Dehydrogenase — a serum enzyme elevated in tissue necrosis and rhabdomyolysis

LSI — Limb Salvage Index

MESS — Mangled Extremity Severity Score

n — number of patients (sample size)

NISSSA — Nerve injury, Ischaemia, Soft-tissue injury, Skeletal injury, Shock, Age score

OTA-OFC — Orthopaedic Trauma Association Open Fracture Classification

PSI — Predictive Salvage Index

ROC — Receiver Operating Characteristic (curve) — a plot of sensitivity against 1-minus-specificity across all possible thresholds; the area under it is the AUC

Sn — Sensitivity — proportion of true amputations correctly identified by the score (true positive rate)

Sp — Specificity — proportion of true salvages correctly identified by the score (true negative rate)

Type IIIA / IIIB / IIIC — Gustilo-Anderson open fracture classification grades: IIIA = adequate soft tissue coverage despite extensive laceration; IIIB = periosteal stripping, bone exposure, requires local or free flap coverage; IIIC = any open fracture with arterial injury requiring repair

VTS — Vetrivel Trauma Score

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