Multidimensional aspects of burn wound treatment

Rashaan, Z.M.

Chapter 3

Three-dimensional imaging is a novel and reliable technique to measure total body surface area

Zjir M. Rashaan [1,2]
Anne Margriet Euser [3]
Paul P.M. van Zuijlen [4,5]
Roelf S. Breederveld [1,2]

[1] Department of Surgery, Leiden University Medical Centre, Leiden, the Netherlands
[2] Burn Centre and Department of Surgery, Red Cross Hospital, Beverwijk, the Netherlands
[3] Jonx, Department of (Youth) Mental Health and Autism, Lentis Psychiatric Institute, Groningen, the Netherlands
[4] Burn Centre and Department of Plastic and Reconstructive Surgery, Red Cross Hospital, Beverwijk, the Netherlands
[5] Department of Plastic and Reconstructive Surgery and MOVE Research Institute, VU University of Amsterdam, Amsterdam, the Netherlands

Burns. 2018 June;44(4):816-822

ABSTRACT

Objective: The aim of this study was to explore the diverse clinimetric aspects of three-dimensional imaging measurements of TBSA in clinical practice compared with the methods currently used in clinical practice (i.e., the rule of nines and palm method) to measure TBSA in clinical practice.

Method: To assess reliability, two independent researchers measured the TBSAs of 48 burn patients using Artec MHT™ Scanner and software. Subsequently, a resident and burn specialist estimated the TBSA of the same wounds using the rule of nines and palm method.

Results: Three-dimensional imaging showed excellent inter-observer reliability, with an intra-class correlation coefficient (ICC) of 0.99, standard error of measurement (SEM) of 0.054, and limits of agreement (LoA) of ± 0.15 x the mean TBSA (between the measurements of two researchers). The inter-observer reliability of the methods used in current clinical practice was less reliable, with an ICC of 0.91, SEM of 0.300 and LoA of ± 0.78 x the mean TBSA. The inter-observer reliability was least reliable between three-dimensional imaging and the residents compared with the Burn specialists for the estimated TBSA, with an ICC of 0.68, SEM of 0.69 and LoA of ± 1.49 x the mean TBSA.

Conclusion: The inter-observer reliability of three-dimensional imaging was superior compared with the rule of nines and palm method.

INTRODUCTION

A correct estimation of burn wound size, which is defined as total body surface area (TBSA), is essential for adequate burn wound management in acute care setting. TBSA determines the need for intravenous fluid resuscitation and whether the patient must be transferred to a specialized burn unit.(1) Moreover, an accurate TBSA estimation is important to manage nutritional support and evaluate treatment efficacy, as well as for research purposes.

In current clinical practice, the rule of nines(2), palm method(3) and Lund and Browder chart(4) are used to estimate TBSA. However, these methods have some limitations. The rule of nines tends to overestimate TBSA.(5) The definition of the palm method is not always clear to the clinicians, and the area of the palm, including the fingers, does not resemble 1% of the body surface area (BSA) in adults, which could lead to overestimation of the burn area. (3, 6-10) The Lund and Browder chart is based on a two-dimensional model, and it does not consider the three-dimensional aspect of the body. However, the inter-rater reliability of this method is better compared to the rule of nines.(5) Moreover, digital Lund & Browder charts showed high reproducibility and fewer estimation errors compared to the paper Lund & Browder chart. (11-13) In general, the reliability of each described method is highly dependent on the size and irregularity of the wound, the body mass index (BMI) of the patient, and the experience of the physician.(6, 14-16)

Recent research indicates that computerized techniques are a promising and likely more accurate method of estimating TBSA. Three-dimensional imaging of the wound surface area is a novel technique that has the potential to overcome the limitations of the described methods to estimate TBSA. With this technique, a full-coloured three-dimensional reconstruction of the burn wound can be performed. TBSA is then obtained from the measured wound surface area and body surface area (BSA).

To assess the applicability of three dimensional imaging in clinical practice, the clinimetric properties, such as reliability, of this method must be investigated first.

In a previous study, we found that three-dimensional imaging using the Artec MHT™ Scanner and software to be a non-invasive and reliable technique for measuring burn wound surface area. The objective of this explorative study was to investigate the inter-observer reliability of three-dimensional imaging for measuring the TBSA in clinical practice compared with methods currently used (rule of nines and palm method).

PATIENTS AND METHODS

Study population

Data were obtained from our validation study.(17) In short, burn patients were included consecutively from the Burn Center of the Red Cross Hospital, Beverwijk, from August 2012 to January 2013. The Red Cross Hospital is one of the three tertiary burn centres in the Netherlands. All burn patients were eligible for study inclusion, except those who had undergone surgical intervention. Informed consent was obtained from all patients before they were included in the study. The local ethics committee approved this study.

Three-dimensional imaging

To measure the burn wound surface area, the Artec MHT™ 3D Scanner, a non-invasive, handheld device (the Artec Group, San Diego, CA, USA), was used. This device projected structured light flashes on a burn wound and then reconstructed the three-dimensional view of the scanned area. This device also provided a coloured image of the scanned area every 15 frames. As a result, a full-coloured three-dimensional reconstruction of the burn wound was obtained. Scans were performed perpendicular to the burn wound at a distance of 40 - 60 cm. Then the software program (Artec 3D Studio 9.0) generated a three-dimensional image of the wound. Thereafter, the clinician had to mark the boundaries of the burn wound on a full-coloured, three-dimensional reconstruction of the wound. Finally, the software program calculated the surface area of the burn wound in mm^2, as marked by the boundaries determined by the clinician. We comprehensively described the technique and procedure of this novel technique in our validation study.(17)

TBSA

To determine the TBSA, the burn surface area measured with three-dimensional-imaging was divided by the body surface area (BSA). The BSA was calculated using the DuBois and DuBois formula (BSA (m^2) = 0.20247 x Height(m)$^{0.725}$ x Weight(kg)$^{0.425}$)(18) for adults and the Haycock formula (BSA (m^2) = 0.024265 x height (cm)$^{0.3964}$ x weight (kg)$^{0.5378}$)(19) for children. To determine the TBSA in clinical practice, a resident and a burn specialist used the rule of nines and palm method to estimate the TBSA. The TBSA estimate performed by a resident and a burn specialist was thought to be most relevant, as for most burn patients, the TBSA is first determined by a resident from a general hospital. When referred to a specialized burn centre, the TBSA is estimated again by a burn specialist.

Study design

Inter-observer reliability of three-dimensional imaging

To assess the inter-observer reliability of determining the TBSA using Artec MHT™ 3D scanner, the TBSAs of all burn wounds were independently calculated by two researchers (A and B). Researcher A and B were researchers at the Burn Centre of Red Cross Hospital and had the

clinical experience of a resident. Both used the Artec MHT™ 3D Scanner to scan the burn surface area. Next, researcher A measured the burn surface area of the scan of researcher B with the Artec 3D software program, and vice versa. This design most accurately reflects clinical practice with divided task and shifts. Finally, TBSAs were calculated by dividing the measured burn surface area by the BSA times a hundred.

Inter-observer reliability of current clinical methods

To put the results of the reliability of three-dimensional imaging in perspective with the reliability of methods used in current clinical practice, the inter-observer reliability of the rule of nines and palm method in estimating the TBSA was determined. Therefore, using the rule of nines and palm method, a resident and a burn specialist also estimated the TBSA of the same series of burn wounds. Four residents and four burn specialists participated in the study.

Inter-observer reliability of three-dimensional imaging and current methods

To study the inter-observer reliability of three-dimensional imaging and current methods, the TBSA of researcher A (measured with an Artec MHT™ 3D scanner), was compared to the TBSA estimated by a resident and a burn specialist using rule of nines and palm method.

Statistical analysis and clinimetrics

The data were analysed using SPSS 20.0 (SPSS Inc., Chicago, IL, USA). Different statistical outcomes were used to study the inter-observer reliability in this study.

Intraclass Correlation Coefficient (ICC)

ICCs were used to estimate the correlation between the TBSAs of the same burn wound estimated by different observers. Wound variance (σ^2 wounds), observer variance (σ^2 observer) and error variance (σ^2 error) were calculated using a linear random-effect model in SPSS to calculate the ICC. The ICC was defined as follows: σ^2wounds / (σ^2 wounds + σ^2 observer + σ^2 error). This ICC measures agreement, as the sample of observers in the study is representative of a large (future) population of observers. (20, 21)

Standard Error of Measurement (SEM)

The standard error of measurement (SEM) was calculated using the following formula: SEM = $\sqrt{}$(σ^2 observer + σ^2 error).

Bland and Altman plot with limits of agreement (LoA)

A modified Bland and Altman plot with the limits of agreement (LoA) was obtained to measure the absolute agreement between the observers and to provide an informative graphical representation of reliability.(20) In this plot, the mean of two estimated TBSA's (x-axis) was plotted against the difference between two estimated or calculated TBSA (y-axis). The LoA

indicated the 95% confidence interval (CI) of the difference between the TBSA estimations or calculations of two observers. Log-transformation of the data was performed when the data were considered to be skewed. Skewed data were considered when the difference between two estimated TBSA increased with the increasing TBSA. However, data were transformed back to the original scale for a better interpretability of the modified Bland and Altman plot in clinical practice, as described by Euser et al.(22) Finally, the LoA was obtained through back transformation of the data (X) and derived from the formula: LoA = $(^2\sqrt{X}+X\pm1.96\sqrt{2}\text{ x SEM})^2$.

RESULTS

Patient characteristics

Forty-eight burn patients were included in this study, 34 adults, and fourteen children < 18 years. Patient characteristics are shown in Table 1.

Table 1. Patients characteristics.

Number of patients	48
Gender, Male (n)	32
Adults	34
Age (years)	
Median (range)	29 (0.8 - 71)
TBSA[1]	
Median (range)	7.0 (0.1 - 7.0)
Burn wounds depth, n	
Partial thickness	34
Full-thickness burns	8
Mixed	6
Burn wound location, n	
Head and neck	6
Trunk (anterior)	8
Trunk (posterior)	6
Upper extremities	20
Lower extremities	18

TBSA: Total body surface area. [1]Estimated at admission by burn specialist.

Three-dimensional imaging

The agreement between the measurement of TBSA between researcher A and B using three-dimensional imaging had an inter-observer ICC of 0.99. The SEM was 0.054. (Table 2) The absolute agreement between both researchers are visually shown in a Bland and Altman plot (Figure 2). The LoA increased with increasing TBSA and the LoA was calculated at 0 ± 0.15 x the mean TBSA. (Figure 1)

Current clinical practice

The agreement between the TBSA measurements of the resident and burn specialist using the rule of nines and palm method had an inter-observer ICC of 0.91. The SEM was 0.30 (Table 2). The LoA increased with increasing TBSA and the LoA was calculated at 0 ± 0.78 x the mean TBSA. Only the LoA is shown in Figure 1.

Table 2. Reliability.

	Three-dimensional imaging[2]	**Current clinical practice**[1]	**Three-dimensional imaging vs current clinical practice**	**Three-dimensional imaging vs current clinical practice**
	Researcher A vs Researcher B	Resident vs Burn specialist	Researcher A vs Burn specialist	Researcher A vs Resident
ICC (range)	0.998	0.91	0.743	0.680
SEM	0.054	0.300	0.437	0.686
LoA	± 0.15 x mean TBSA	± 0.78 x mean TBSA	± 1.08 x mean TBSA	± 1.49 x mean TBSA

ICC: Intraclass Correlation Coefficient, SEM: Standard Error of measurement, LoA: Limits of Agreement. [1]Both rule of nines and palm method were used to estimate percentage of TBSA, [2]Artec MHT™ 3D Scanner was used to measure TBSA.

Three-dimension imaging vs current clinical practice

The agreement between researcher A using three-dimensional imaging and the burn specialist using the rule of nines and palm method had an inter-observer ICC of 0.74. The SEM was 0.44 (Table 2). The agreement between researcher A and the burn specialist is shown in a Bland and Altman plot (Figure 2). The LoA increased as the TBSA increased, and the LoA was calculated at ± 1.08 x the mean TBSA. (Figure 2).

The agreement between researcher A using three-dimensional imaging and resident using the rule of nines and palm method had an inter-observer ICC of 0.68. The SEM was 0.69 (Table 2) The agreement between researcher A and the resident is shown in a Bland and Altman plot (Figure 2). The LoA increased with as the TBSA increased, and the LoA was calculated at ± 1.49 x the mean TBSA. (Figure 2) The agreement between the measurements of researcher B using three-dimensional imaging and the clinicians was comparable with the results of researcher A.

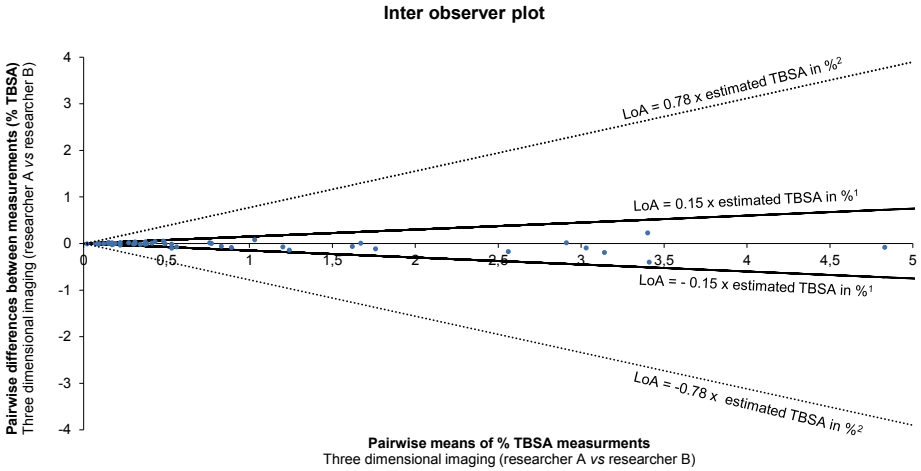

Figure 1. Bland and Altman plot presenting the inter-observer agreement between two researchers using three-dimensional imaging for means % TBSA. [1] Limits of agreement (LoA) between two researchers using three-dimensional imaging method, [2] Limits of agreement (LoA) between resident and burn specialist using rule of nines and palm method.

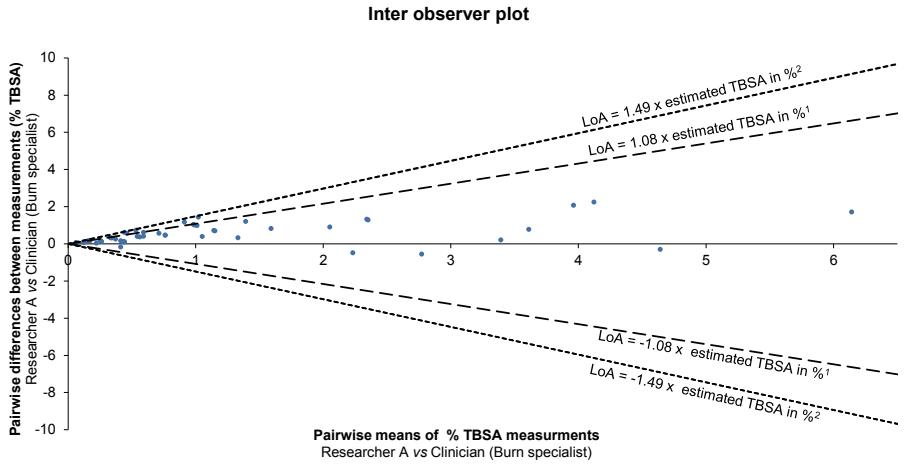

Figure 2. Bland and Altman plot presenting the inter-observer agreement between researcher A using three-dimensional imaging and burn specialist using the rule of nines and palm method for means percentage of TBSA. [1] Limits of agreement (LoA) between researcher A and burn specialist, [2] Limits of agreement (LoA) between researcher A and resident.

DISCUSSION

In this explorative study, three-dimensional imaging, using an Artec MHT™ Scanner and software, was found to be a reliable method for measuring TBSA of burn wounds in clinical practice. The inter-observer reliability of three-dimensional imaging was considerably better than that of a resident and a burn specialist using the rule of nines and palm method to measure TBSA. The inter-observer reliability between three-dimensional imaging and methods used in current clinical practice by a resident was less reliable compared with three-dimensional imaging and methods used in current clinical practice by a burn specialist in determining TBSA.

Strength and limitations

This study is the first study that describes three-dimensional imaging for measurement of the TBSA. An important advantage of three-dimensional imaging is the direct full-coloured three-dimensional reconstruction of the wound without any pre-specified three-dimensional model. A pre-specified three-dimensional model is a potential source of bias. While exploratory, this study aimed to investigate clinimetric properties of three-dimensional imaging in more detail by calculating not only ICC but also SEM and LoA to measure inter-observer reliability. ICC is a popular parameter for measuring reliability, however, it has two important limitations. First, by increasing the range of measurements and, thus, the variation between wounds, ICC can be artificially inflated. Second, ICC does not provide information on the absolute size of the measurement error, which is important in the clinical setting.(23) Therefore, estimating several different clinimetric properties of a method, for example a Bland and Altman plot with LoA in which the absolute measurement error is shown, is essential.

Our study had several limitations. First, we cannot specify the variation in reliability if researcher A and B measured their own scans instead of measuring one another's scans. Nevertheless, introducing this uncontrolled source of variation was justified in the current study design because this study was aimed toward clinical practice, in which case, it would be most likely that one physician performs the scan and another physician measures the TBSA. However, excellent reliability was obtained despite the current study design. In theory, the reliability would be greater if the observers performed and measured their own scans. Second, no intra-observer reliability was performed because in general, intra-observer reliability is higher than inter-observer reliability. (24) Third, for practical reasons, no validity study was performed for the TBSA measurements. However, in a previous study, three-dimensional imaging was found to be both valid and reliable for measuring the burn wound surface area. Fourth, in a recent study, a close correlation ($r > 0.95$) and no significant difference were observed between the mean BSA values calculated by Ct-scan (gold standard) and the formulas used in this study (DuBois & DuBois and Haycock) for BSA measurements.(25) These results suggests that the formulas used in our study to calculate BSA are acceptable. In addition, while not

objectively assessed, the measurement procedure of performing a scan took no longer than two minutes per patient. However, post-processing the data and measuring the wound surface area took between 15 minutes and one hour. Note that the Artec 3D software is constantly under development, and newer versions provides significant improvements regarding the post-processing time. Finally, given the range of the studied TBSA (< 6% TBSA) in this study, the results might not be generalized to higher TBSA.

Comparison with literature

To the best of our knowledge, three-dimensional reconstruction of a burn wound for the purpose of measuring TBSA has not been previously described. Therefore, there could be no direct comparison with the characteristics of comparable methods. However, two studies have described using software with pre-defined three-dimensional models to measure TBSA (BurnCase 3D and BAI).(26, 27) Only one study (BurnCase 3D) has investigated the inter-rater reliability of their method, with an ICC of 0.98.

Our results confirmed the finding from various studies describing poor correlation between TBSA estimates between referring physicians (comparable with the estimation made by the resident in our study) and burn specialists.(28-30) An LoA of 0 ± 0.78 x the mean TBSA between the residents and burn specialists in our study could lead to serious under- or overestimation of TBSA. Errors in estimating TBSA could result in a miscalculation of the need for intravenous fluid resuscitation and uncertainty whether the patient should transferred to a specialized burn unit.

To put the reliability of three-dimensional imaging in perspective, comparison with the reliability of current methods in clinical practice is obligatory. Interestingly, the inter-observer ICC of three-dimensional imaging and methods used in current clinical setting were both > 0.90, which indicates high reliability. However, as previously described, ICC has limitations. In this study, three-dimensional imaging showed superior results, as indicated by smaller SEM and much smaller LoA compared with methods currently used in clinical practice.

In the literature, no comparisons were found between three-dimensional imaging and current methods used in clinical practice to estimate TBSA. However, Prieto et al. have compared BAI with the rule of nines. The ICCs of BAI for the estimation of TBSA for the superficial and deep burns were 0.55 and 0.77, respectively.(27) Furthermore, in another study, the rule of nines and palm method were found to overestimate the TBSA by 38% and 37%, respectively, compared with BurnCase 3D.(31)

Future perspective

Future study on three-dimensional imaging should concentrate on more critical appraisals of the clinimetric properties of the method. Our results are encouraging, and validation studies should be performed. Finally, the implication of using Artec MHT™ Scanner and software in clinical practice for the clinical decisions, such as correct measurement of TBSA and subsequent patient outcomes (e.g., wound healing and mortality) should be studied and compared with the results of current methods.

CONCLUSION

In this explorative study three-dimensional imaging, using Artec MHT™ Scanner and software, was found to be superior compared with methods currently used in clinical practice (i.e., the rule of nines and palm method) for measuring TBSA. The inter-observer reliability between three-dimensional imaging and methods used in current clinical practice by residents was less reliable compared with three-dimensional imaging and methods currently used in clinical practice by burn specialists to determine TBSA.

Acknowledgments

The authors would like to thank K.L. Gardien, MD, M.E.H. Jaspers, MD, C.M. Stekelenburg, MD, PhD, F.R. Tempelman, MD, A.F. Vloemans, MD, PhD and M.B. van der Wal, MD, PhD for their participation in the TBSA measurements and review of the study protocol.

REFERENCES

1. Cartotto RC, Innes M, Musgrave MA, Gomez M, Cooper AB. How well does the Parkland formula estimate actual fluid resuscitation volumes? *The Journal of burn care & rehabilitation* 2002;23(4):258-65.
2. WALLACE AB. The exposure treatment of burns. *Lancet* 1951;1(6653):501-4.
3. Sheridan RL, Petras L, Basha G, Salvo P, Cifrino C, Hinson M, et al. Planimetry study of the percent of body surface represented by the hand and palm: sizing irregular burns is more accurately done with the palm. *The Journal of burn care & rehabilitation* 1995;16(6):605-6.
4. Lund CC BN. The estimation of areas of burns. *Surg Gynecol Obstet* 1944;79:352-258.
5. Wachtel TL, Berry CC, Wachtel EE, Frank HA. The inter-rater reliability of estimating the size of burns from various burn area chart drawings. *Burns* 2000;26(2):156-70.
6. Jose RM, Roy DK, Vidyadharan R, Erdmann M. Burns area estimation-an error perpetuated. *Burns* 2004;30(5):481-2.
7. van der Wal MB, Tuinebreijer WE, Bloemen MC, Verhaegen PD, Middelkoop E, van Zuijlen PP. Rasch analysis of the Patient and Observer Scar Assessment Scale (POSAS) in burn scars. *Quality of life research : an international journal of quality of life aspects of treatment, care and rehabilitation* 2012;21(1):13-23.
8. Rossiter ND, Chapman P, Haywood IA. How big is a hand? *Burns* 1996;22(3):230-1.
9. Nagel TR, Schunk JE. Using the hand to estimate the surface area of a burn in children. *PediatrEmergCare* 1997;13(4):254-5.
10. Amirsheybani HR, Crecelius GM, Timothy NH, Pfeiffer M, Saggers GC, Manders EK. The natural history of the growth of the hand: I. Hand area as a percentage of body surface area. *Plastic and reconstructive surgery* 2001;107(3):726-33.
11. Williams JF, King BT, Aden JK, Serio-Melvin M, Chung KK, Fenrich CA, et al. Comparison of traditional burn wound mapping with a computerized program. *JBurn Care Res* 2013;34(1):e29-e35.
12. Neuwalder JM, Sampson C, Breuing KH, Orgill DP. A review of computer-aided body surface area determination: SAGE II and EPRI's 3D Burn Vision. *The Journal of burn care & rehabilitation* 2002;23(1):55-9; discussion 4.
13. Berry MG, Goodwin TI, Misra RR, Dunn KW. Digitisation of the total burn surface area. *Burns* 2006;32(6):684-8.
14. Knaysi GA, Crikelair GF, Cosman B. The role of nines: its history and accuracy. *PlastReconstrSurg* 1968;41(6):560-3.
15. Miller SF, Finley RK, Waltman M, Lincks J. Burn size estimate reliability: a study. *The Journal of burn care & rehabilitation* 1991;12(6):546-59.
16. Berry MG, Evison D, Roberts AH. The influence of body mass index on burn surface area estimated from the area of the hand. *Burns* 2001;27(6):591-4.
17. Rashaan ZM, Stekelenburg CM, van der Wal MB, Euser AM, Hagendoorn BJ, van Zuijlen PP, et al. Three-dimensional imaging: a novel, valid, and reliable technique for measuring wound surface area. *Skin research and technology : official journal of International Society for Bioengineering and the Skin* 2016;22(4):443-50.
18. Du Bois D, Du Bois EF. A formula to estimate the approximate surface area if height and weight be known. 1916. *Nutrition* 1989;5(5):303-11; discussion 12-3.

19. Haycock GB, Schwartz GJ, Wisotsky DH. Geometric method for measuring body surface area: a height-weight formula validated in infants, children, and adults. *The Journal of pediatrics* 1978;93(1):62-6.
20. de Vet HC, Terwee CB, Knol DL, Bouter LM. When to use agreement versus reliability measures. *JClinEpidemiol* 2006;59(10):1033-9.
21. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychological bulletin* 1979;86(2):420-8.
22. Euser AM, Dekker FW, le CS. A practical approach to Bland-Altman plots and variation coefficients for log transformed variables. *JClinEpidemiol* 2008;61(10):978-82.
23. Stekelenburg CM, Jaspers ME, Niessen FB, Knol DL, van der Wal MB, de Vet HC, et al. In a clinimetric analysis, 3D stereophotogrammetry was found to be reliable and valid for measuring scar volume in clinical research. *Journal of clinical epidemiology* 2015;68(7):782-7.
24. Streiner DL, Norman RN. *Health Measurement Scales: A Practical Guide to Their Development and Use*. Oxford, United Kingdom: Oxford University Press, 2008.
25. Villa C, Primeau C, Hesse U, Hougen HP, Lynnerup N, Hesse B. Body surface area determined by whole-body CT scanning: need for new formulae? *Clinical physiology and functional imaging* 2017;37(2):183-93.
26. Parvizi D, Giretzlehner M, Wurzer P, Klein LD, Shoham Y, Bohanon FJ, et al. BurnCase 3D software validation study: Burn size measurement accuracy and inter-rater reliability. *Burns* 2016;42(2):329-35.
27. Prieto MF, Acha B, Gomez-Cia T, Fondon I, Serrano C. A system for 3D representation of burns and calculation of burnt skin area. *Burns* 2011;37(7):1233-40.
28. Baartmans MG, van Baar ME, Boxma H, Dokter J, Tibboel D, Nieuwenhuis MK. Accuracy of burn size assessment prior to arrival in Dutch burn centres and its consequences in children: a nationwide evaluation. *Injury* 2012;43(9):1451-6.
29. Giretzlehner M, Dirnberger J, Owen R, Haller HL, Lumenta DB, Kamolz LP. The determination of total burn surface area: How much difference? *Burns* 2013;39(6):1107-13.
30. Chan QE, Barzi F, Cheney L, Harvey JG, Holland AJ. Burn size estimation in children: still a problem. *Emergency medicine Australasia : EMA* 2012;24(2):181-6.
31. Parvizi D, Giretzlehner M, Dirnberger J, Owen R, Haller HL, Schintler MV, et al. The use of telemedicine in burn care: development of a mobile system for TBSA documentation and remote assessment. *Annals of burns and fire disasters* 2014;27(2):94-100.