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Observational Study

Assessment of quadriceps muscle thickness using bedside ultrasonography by nurses and physicians in the intensive care unit: Intra- and inter-operator agreement

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Author contributions: Kumar R and Shah TH contributed equally in performance of the acquisition and analysis of the ultrasonography images; Hadda V designed the study, performed acquisition and analysis of the ultrasonography images, and wrote the manuscript; Tiwari P, Mittal S, Madan K and Mohan A contributed in critical appraisal of the study design, literature search, and editing of the manuscript; Khan MA performed the statistical analysis.

Institutional review board

statement: The study protocol was approved by the institutional ethics committee of All India Institute of Medical Sciences, New Delhi, India (Ref. No. IEC-435/02.09.2016, RP-52/2016).

Informed consent statement: All study participants or their legal guardians provided written informed consent prior to participation in the study.

Conflict-of-interest statement: All

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Abstract**BACKGROUND**

Data regarding the agreement among multiple operators for measurement of quadriceps muscle thickness by bedside ultrasonography (USG) are sparse.

AIM

To statistically assess the agreement among 5 operators for measurement of quadriceps muscle thickness on bedside USG.

METHODS

This was a cross-sectional observational study. The 5 operators of varied experience (comprised of 1 critical care consultant, 2 fellows, and 2 nurses) independently measured quadriceps muscle thickness in triplicate for 45 critically ill patients each, using USG. Intra- and interrater agreement rates among the 5 operators were assessed using intraclass correlation coefficient (ICC) and expressed with 95% confidence interval (CI).

RESULTS

The 5 operators produced a total of 135 readings and 675 observations for ICC calculations to determine the intraoperator and interoperator variations respectively. For intraoperator agreement, the overall ICC (95%CI) was 0.998 (0.997, 0.999) for operator 1, 0.998 (0.997, 0.999) for operator 2, 0.997 (0.995, 0.999) for operator 3, 0.999 (0.998, 0.999) for operator 4, and 0.998 (0.997, 0.999) for

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operator 5. For interoperator agreement, the overall ICC (95%CI) was 0.977 (0.965, 0.986; $P < 0.001$) for reading 1, 0.974 (0.960, 0.984; $P < 0.001$) for reading 2, and 0.975 (0.961, 0.985; $P < 0.001$) for reading 3.

CONCLUSION

USG measurement of quadriceps muscle thickness was not dependent on clinical experience, supporting training for nurses in it.

Key words: Agreement; Intensive care unit; Critical illness; Muscle thickness; Quadriceps muscle; Ultrasonography

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Core tip: Ultrasonography-measured quadriceps muscle thickness may be an early marker of adverse outcome among patients in the intensive care unit (ICU). However, while the technological approach is available for routine bedside use in the ICU, its application in daily care can increase the workload of ICU physicians. In this study, we found that quadriceps muscle thickness measurement by using ultrasonography can be done reliably by nurses, to a degree that is comparable to that of ICU fellows and a critical care consultant. These results suggest that nurses may be trained easily and used for ultrasonography measurement of quadriceps muscle thickness.

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INTRODUCTION

Patients admitted to intensive care units (ICUs) exhibit significant loss of muscle mass and function during their hospital stay^[1,2]. Inactivity of muscles, poor nutrition, and various proinflammatory cytokines associated with the systemic inflammatory response may be responsible for these losses^[1,2]. The loss of muscle mass, in particular, has been associated with various adverse clinical outcomes among the ICU patient population, including prolonged mechanical ventilation, reintubation, mortality, and increased cost of care^[2,3].

Accurate assessment of muscle functions and timely diagnosis of muscle dysfunction, together, are crucial for effective preventive or therapeutic interventions. The Medical Research Council (MRC) grading system and anthropometry are commonly applied to clinically assess the muscle mass and functions. The MRC grading requires patients to be fully alert, while anthropometry assessment requires only normal hydration status. Since the majority of critically ill patients have depressed mental status and altered hydration, both of these tools are insensitive and unreliable for assessment of the muscle mass and functions in the ICU patients^[4,5]. Researchers have, however, shown that muscle thickness correlates with muscle function^[6]. Muscle thickness can be measured accurately using tools such as dual-energy X-ray absorptiometry (DEXA), magnetic resonance imaging (MRI), and computer tomography (CT)^[5,7]. Thus, data obtained through these scans provide information regarding muscle functions independent of patients' level of alertness, effort, and hydration status. However, these tools remain of limited use for critically ill patients on multiple life-support therapies.

Recently, ultrasonography (USG) has been proposed as a promising tool for the assessment of skeletal muscle thickness^[8-10]. USG has the advantage of being a bedside technology, appropriate for single-time measurement, and useful for studying trends in a patient's status. Importantly, there is also no risk of radiation exposure with USG. The quadriceps muscles are bulky muscle tissue, usually free of clinical monitoring devices and intravenous lines, and can be used for thickness assessment by USG. Preliminary data from others have also suggested that USG-measured quadriceps muscle thickness can be an early marker of adverse outcome among critically ill

patients^[9]. Thus, it is likely that the role of USG in assessment of muscle functions will expand among the critically ill patient population. However, addition of USG to daily care in the ICU is also likely to increase the workload of the treating physicians. If the paramedical staff, especially nurses, can perform the USG assessment of muscle thickness, it will help to counter this hindering factor. Before asking nurses to use USG for this purpose though, the reliability of their measurements, as compared to the more highly expert staff, should be established. This study was hence designed to assess intra- and interoperator reliability of measurements of quadriceps muscle thickness using USG data obtained by 2 nurses and 3 physicians who practice in the ICU.

MATERIALS AND METHODS

This study was conducted following good clinical practices proposed for biomedical research involving human subjects^[11]. Prior approval of the study protocol was sought from the institute's ethics committee for research protocols (Ref. No. IEC-435/02.09.2016, RP-52/2016). All patients provided a written informed consent for participation in the study.

Study design and patients

This cross-sectional study included critically ill adult patients (age > 18 years) admitted under the Pulmonary Medicine Services of a tertiary care teaching institute between July 2016 and June 2017. Exclusion criteria were primary neuromuscular diseases (*i.e.*, myopathy, neuropathy, stroke, *etc.*), an amputated limb, and refusal of participation in the study.

Equipment

The measurements were made using B-mode USG with a 5.0-13.0 MHz linear array probe (VF 13-5) on an ACUSON X300™ ultrasound (Siemens Healthineers, Erlangen, Germany).

Operators

There were 5 operators who independently assessed the quadriceps muscle thickness on USG. These operators represented faculty (a critical care consultant; $n = 1$), fellows ($n = 2$), and nurses ($n = 2$). The faculty member (VH) had an experience of > 5 years. Both fellows (RK, THS) were trained and actively using USG in the ICU for > 2 years. Both nurses were naïve to USG, and as such were given a short training regarding image acquisition and measurement of muscle thickness on 5-10 patients, prior to start of the study.

Muscle thickness measurements

Quadriceps muscle thickness measurements were done following the previously published protocol^[9,12,13]. All measurements were carried out on the right thigh, with the patient in supine position and having the knee extended and toes facing the ceiling. The posture was maintained until all images were acquired. A circumferential mark was put at the midway between the tip of the greater trochanter and the lateral joint line of the knee. The linear ultrasound probe was placed on this circumferential line, perpendicular to the skin, and the probe was moved along the line until a suitable image was obtained. Then, the point corresponding to the center of the probe was marked with a vertical line. This point was used as the reference point for all subsequent measurements. The thickness of the quadriceps muscle group (vastus lateralis, rectus femoris, and vastus medialis) between the superficial fat-muscle interface and the femur was measured anteriorly. Each of the 5 operators took three measurements, independently. None of the 5 operators was aware of the muscle thickness measurement values obtained by any of the 4 others.

Statistical analysis

The intraclass correlation coefficient (ICC) was calculated for intra- and interoperator variability among the 5 operators. For intraoperator variation, the ICC was calculated for the three pairs of measurements (1st and 2nd, 1st and 3rd, and 2nd and 3rd) made by each operator. Interoperator variation was assessed using ICC for 10 possible pairs of operators for each observation. The ICCs were expressed with 95% confidence intervals. A P value of < 0.05 was considered significant. Mean [\pm standard deviation (SD)] was applied as appropriate. All statistical analyses were performed on SPSS for Windows software (version 24; IBM Corp., Armonk, NY, United States).

RESULTS

Baseline characteristics

This study included 45 critically ill patients admitted to the pulmonary medicine ward or ICU. There were 30 males (66.6%). The mean (\pm SD) age of participants was 54.95 (\pm 15.97) years and that of Acute Physiology and Chronic Health Evaluation score and Simplified Acute Physiology Score was 14.66 (\pm 4.57) and 2.6 (\pm 1.37) respectively.

Muscle thickness measurements

Each of the 5 operators took three readings of quadriceps muscle thickness, which varied from 17.11 mm to 17.87 mm. The measurements taken by operator 3 (Fellow; TS) had the highest values. The collective mean (\pm SD) quadriceps thickness measurements obtained by all operators on three different attempts are shown in [Table 1](#).

Intraoperator reliability

For each operator, there were 135 (3×45) readings for calculation of ICC to assess the intraoperator variation. The resultant ICCs for all of the three possible pairs (1st and 2nd, 1st and 3rd, and 2nd and 3rd) of quadriceps muscle thickness measurements taken by each operator were close to 1 (lowest being 0.997, to highest of 0.999); similarly, the overall ICC was excellent for each operator's intraoperator reliability separately ([Table 2](#)).

Interoperator reliability

There were a total 675 observations for analysis of ICC of interoperator variation. The minimum value of ICC for interoperator variation was 0.955, while the maximum value was 0.988. The results of pairwise and overall ICCs for interoperator variation are shown in [Table 3](#).

DISCUSSION

Our study results demonstrate an excellent intra- and interoperator agreement for quadriceps muscle thickness measured on bedside USG by 2 nurses and 3 ICU physicians, representing varied clinical experience levels. The excellent intra- and interoperator agreement rates found indicate that nurses may be utilized for assessment of quadriceps muscle thickness in this setting.

Availability of USG in general has increased the precision and reduced the complication rates of various procedures carried out in the ICU setting^[14,15]. Indeed, USG was recently proposed to be a useful tool for assessment of muscle mass in the form of muscle thickness^[8-10]. It seems reasonable to include bedside USG in daily care for assessment of muscle thickness among patients in the ICU; however, inclusion of USG assessment for muscle thickness will also serve to increase the workload of the critical care fellows and consultants. Nurses working in the ICU contribute immensely to the provision of care given to the critically ill patient population in this setting; yet, the services of these highly-skilled workers likely remain underutilized.

Nurses represent potential manpower that can be readily trained for the measurement of quadriceps muscle thickness on USG. In consideration of this and the fact that USG measurements are operator-dependent (with potential for significant variation), our results support the notion that nurses can measure quadriceps muscle thickness to a similar excellent degree of the more highly trained physician-level staff in our facility. It should be noted, here, that both of our nurses were naïve to USG and both received only a short training course involving 5-10 patients prior to study participation. Thus, only a short training was required for our nurses to carry out appropriate assessment of quadriceps muscle thickness using USG; we suggest that this may be the case with the ICU nursing staff of other critical care hospitals and departments. The importance of expanding our finding to other facilities is highlighted by the observation that quadriceps muscle thickness may be an early predictor of adverse outcome among critically ill patients^[9].

The comparison of measurements taken by operators naïve to USG (2 nurses) with those of experienced operators (consultant and fellows) is the greatest strength of our study. This design provided data from a real-time scenario, when a clinically-trained but USG-naïve operator was asked to take measurement after a short training course; the data from the experienced operator verified the reproducibility of the measurements obtained by the former. There have been other studies which have shown minimal variability when > 1 operator assessed the quadriceps muscle thickness on USG^[10,13]. Also, in our study, the quadriceps muscle thicknesses were

Table 1 Quadriceps thickness measured by 5 operators in a critical care setting

| Operator | | Thickness measured on three different attempts, mean (\pm SD) mm | | |
|----------|------------|---|---------------------|---------------------|
| ID | Level | 1 st | 2 nd | 3 rd |
| 1 | Consultant | 17.14 (\pm 6.64) | 17.49 (\pm 6.83) | 17.44 (\pm 6.82) |
| 2 | Fellow | 17.23 (\pm 6.81) | 17.28 (\pm 6.92) | 17.17 (\pm 6.81) |
| 3 | Fellow | 17.82 (\pm 6.73) | 17.87 (\pm 6.81) | 17.80 (\pm 6.77) |
| 4 | Nurse | 17.11 (\pm 6.54) | 17.28 (\pm 6.49) | 17.35 (\pm 6.57) |
| 5 | Nurse | 17.52 (\pm 6.64) | 17.42 (\pm 6.67) | 17.52 (\pm 6.71) |

SD: Standard deviation.

measured in all patients by each of the 5 operators, allowing for direct comparative analysis of all observations. Moreover, all measurements by all 5 operators were taken independently, without each operator being aware of the results of measurement by the other 4 operators. The blinding of operators from each other's results at the time of measurement further added to the reliability of the measurement data obtained by each.

There are certainly a few limitations to our study design that must be considered in the generalization of our findings. First, there was no radiologist included as an operator. Such might have helped in assessing the agreement of nonradiologist operators with the most experienced operator of USG. It is undebatable that radiologists are the most experienced staff to operate USG; however, they are not available round the clock in the ICU. Hence, results related to operators who stay in the ICU on a regular schedule, and are likely to use USG in this setting, are more useful for a day-to-day care point of view. In our ICU there is no dedicated radiologist available round the clock, which laid beneath our decision to not include a radiologist as an operator for this study. Second, there was no "gold-standard" used to check the accuracy of the measurement of muscle thicknesses taken by our 5 operators. Quadriceps muscle thickness measurements using CT, MRI or DEXA scan are considered "gold-standard", but many patients admitted to the ICU are too sick to be physically shifted for these investigations. Therefore, all these tools are of no use in this setting. Data have shown, however, that measurements obtained by USG have good correlation with those obtained by CT, MRI or DEXA scan^[16]. Importantly, USG can be carried out at the bedside, bolstering the relevance of our findings in this setting.

In conclusion, quadriceps muscle thickness can be measured by nurses, with excellent reproducibility of measurements compared with readings taken by a critical care consultant and fellows. These results suggest that nurses may be trained for measurement of quadriceps muscle thickness on USG in the critical care setting.

Table 2 Intraclass correlation coefficient for intraoperator variation among five operators

| Operator | | Measurements | ICC (95%CI); P value | Cronbach's alpha |
|----------|------------|------------------------------------|-------------------------------|------------------|
| ID | Level | | | |
| 1 | Consultant | 1 st vs 2 nd | 0.997 (0.992-0.999); < 0.0001 | 0.998 |
| | | 1 st vs 3 rd | 0.997 (0.993-0.998); < 0.0001 | 0.997 |
| | | 2 nd vs 3 rd | 0.998 (0.996-0.999); < 0.0001 | 0.998 |
| | | Overall | 0.998 (0.997-0.999); < 0.0001 | 0.997 |
| 2 | Fellow | 1 st vs 2 nd | 0.997 (0.995-0.998); < 0.0001 | 0.997 |
| | | 1 st vs 3 rd | 0.997 (0.995-0.997); < 0.0001 | 0.997 |
| | | 2 nd vs 3 rd | 0.997 (0.995-0.998); < 0.0001 | 0.997 |
| | | Overall | 0.998 (0.997-0.999); < 0.0001 | 0.998 |
| 3 | Fellow | 1 st vs 2 nd | 0.997 (0.995-0.999); < 0.0001 | 0.997 |
| | | 1 st vs 3 rd | 0.997 (0.995-0.999); < 0.0001 | 0.997 |
| | | 2 nd vs 3 rd | 0.998 (0.996-0.998); < 0.0001 | 0.998 |
| | | Overall | 0.997 (0.995-0.999); < 0.0001 | 0.998 |
| 4 | Nurse | 1 st vs 2 nd | 0.998 (0.996-0.999); < 0.0001 | 0.998 |
| | | 1 st vs 3 rd | 0.997 (0.995-0.999); < 0.0001 | 0.998 |
| | | 2 nd vs 3 rd | 0.999 (0.998-0.999); < 0.0001 | 0.999 |
| | | Overall | 0.999 (0.998-0.999); < 0.0001 | 0.999 |
| 5 | Nurse | 1 st vs 2 nd | 0.998 (0.996-0.999); < 0.0001 | 0.998 |
| | | 1 st vs 3 rd | 0.997 (0.995-0.998); < 0.0001 | 0.997 |
| | | 2 nd vs 3 rd | 0.998 (0.996-0.999); < 0.0001 | 0.998 |
| | | Overall | 0.998 (0.997-0.999); < 0.0001 | 0.998 |

CI: Confidence interval; ICC: Intraclass correlation coefficient.

Table 3 Intraclass correlation coefficients for intraoperator variation among five operators for interoperator variation among 5 operators

| Operator ¹ comparison | ICC (95%CI); P value | | |
|----------------------------------|-------------------------------|-------------------------------|-------------------------------|
| | 1 st measurement | 2 nd measurement | 3 rd measurement |
| 1 vs 2 | 0.979 (0.961, 0.988); < 0.001 | 0.976 (0.956, 0.987); < 0.001 | 0.977 (0.958, 0.987); < 0.001 |
| 1 vs 3 | 0.978 (0.960, 0.988); < 0.001 | 0.978 (0.960, 0.988); < 0.001 | 0.977 (0.959, 0.987); < 0.001 |
| 1 vs 4 | 0.965 (0.938, 0.981); < 0.001 | 0.955 (0.920, 0.975); < 0.001 | 0.962 (0.932, 0.979); < 0.001 |
| 1 vs 5 | 0.979 (0.963, 0.989); < 0.001 | 0.967 (0.942, 0.982); < 0.001 | 0.971 (0.948, 0.984); < 0.001 |
| 2 vs 3 | 0.988 (0.979, 0.994); < 0.001 | 0.984 (0.971, 0.991); < 0.001 | 0.982 (0.967, 0.990); < 0.001 |
| 2 vs 4 | 0.966 (0.938, 0.981); < 0.001 | 0.963 (0.933, 0.979); < 0.001 | 0.966 (0.939, 0.981); < 0.001 |
| 2 vs 5 | 0.980 (0.964, 0.989); < 0.001 | 0.975 (0.956, 0.986); < 0.001 | 0.978 (0.960, 0.988); < 0.001 |
| 3 vs 4 | 0.966 (0.939, 0.981); < 0.001 | 0.969 (0.945, 0.983); < 0.001 | 0.968 (0.942, 0.982); < 0.001 |
| 3 vs 5 | 0.983 (0.969, 0.991); < 0.001 | 0.979 (0.962, 0.988); < 0.001 | 0.980 (0.964, 0.989); < 0.001 |
| 4 vs 5 | 0.988 (0.978, 0.993); < 0.001 | 0.989 (0.980, 0.994); < 0.001 | 0.985 (0.973, 0.992); < 0.001 |
| Overall | 0.977 (0.965, 0.986); < 0.001 | 0.974 (0.960, 0.984); < 0.001 | 0.975 (0.961, 0.985); < 0.001 |

¹1: Consultant; 2 and 3: Fellow; 4 and 5: Nurse. CI: Confidence interval; ICC: Intraclass correlation coefficient.

ARTICLE HIGHLIGHTS

Research background

Nurses can measure quadriceps muscle thickness using ultrasonography (USG). However, the data regarding the reliability of such measurements are sparse.

Research motivation

The inclusion of USG for assessment of quadriceps muscle thickness on a daily basis would add, remarkably, to the workload on intensive care unit (ICU) physicians. Reliable measurement of quadriceps muscle thickness by USG from nurse operators would reduce the workload of

physicians working in the ICU.

Research objectives

To evaluate the reliability of measurements of quadriceps muscle thickness using USG data obtained by critical care-setting nurses.

Research methods

In this cross-sectional observational study, 5 operators (comprised of 1 critical care consultant, 2 fellows, and 2 nurses) independently measured quadriceps muscle thickness on ICU patients by using USG. The experience of using USG was variable among the 5 operators. The consultant and 2 fellows had experience of > 5 years and 2 years, respectively. Both nurses were naïve to USG, and they were provided a short training course involving 5-10 patients before the actual start of the study. Each operator took three readings of each patient's quadriceps muscles thickness on USG, independently. Assessment of agreement for measurements taken by all 5 operators was done by computing the intraclass correlation coefficient (ICC) and expressed with the corresponding 95% confidence interval (CI).

Research results

We included 45 critically ill patients in this study. The quadriceps muscle thickness measured by the 2 nurses closely resembled those obtained by the critical care consultant and 2 fellows. The overall ICC (95% CI) for interoperator agreement for the 1st, 2nd and 3rd readings were 0.977 (0.965, 0.986; $P < 0.001$), 0.974 (0.960, 0.984; $P < 0.001$) and 0.975 (0.961, 0.985; $P < 0.001$) respectively.

Research conclusions

Critical care nurses can measure quadriceps muscle thickness on bedside USG, with their measurements having excellent reliability when compared to those from a critical care consultant and fellows.

Research perspectives

The current study adds to the expanding body of literature on the use of bedside USG in critical care settings. The study's results suggest that nurses in the ICU setting may successfully perform USG assessment of quadriceps muscle thickness. Feasibility of a nurses-led assessment of quadriceps muscle thickness should be explored further in studies involving larger populations of staff and patients and more various critical care settings.

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