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Published in:
Program & Abstracts: 15th Annual Meeting of the Danish Society of Biomechanics.

Publication date:
2023

Quest for Accuracy: Progressing Towards Optimal Ultrasound Settings for Bone-Soft Tissue Interface Identification

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INTRODUCTION

Accurate bone movement tracking under varying loads is vital for determining bone kinematics, which must be precise to within 1 degree or 1 mm for clinical applications [1]. However, conventional methods rely on costly, invasive, and limited-field-of-view medical imaging such as X-ray imaging which restricts the clinical usage. An alternative, non-invasive approach is an ultrasound-based system for comprehensive 3D joint kinematics quantification.
Recent research by Niu et al. showcased the viability of using A-mode ultrasound probes for knee joint kinematics recording, achieving a maximum RMSE of 3.44 degrees for rotations and 4.88 mm for translations using 30 probes [2]. However, utilizing A-mode probes poses challenges in accurately distinguishing bone peaks amid amplitude peaks influenced by intricate soft tissue interactions [3,4].
This investigation focuses on the impact of varied ultrasound transmission settings on bone peak detection, intending to optimize the non-invasive utility of ultrasound in joint kinematics assessment.

METHODS

A 7.5 MHz dual-element A-mode probe was used to evaluate ultrasound settings from Table 1, facilitated by the Verasonics Vantage 32LE System.
The study involved a cadaveric lower limb specimen, thawed a day before the experiment, and initiated with the probe placed at the femoral trochanter major following palpation.

The arrangement was located within a CT scanner to obtain images for ascertaining the true distance between the probe and the bone surface, derived from segmented CT images. The experimental data analysis procedure consists of:

Identifying and graphing peaks that matched specific characteristics from previous experiments based on peak width and prominence.
Choosing the presumed bone peak.
Conducting a comparison with the ground truth distance.

RESULTS AND DISCUSSION

Among the peaks for every setting meeting the width, amplitude, and prominence criteria values, one was selected based on the comprehensive pattern of the received data and then compared to the ground truth of 9.81 mm. The results can be seen in Table 2.

Table 1 – peak distances for some of the settings in mm.

The peak selection hinges on data shape and curvature. The optimal bone peak is envisioned as sharp, with high amplitude, devoid of local minima, and showing minimal signal trailing due to the bone's pronounced attenuation. Nonetheless, the interaction of bone with sound may induce blurring, attributed to the reverberation phenomenon involving strong parallel reflectors.

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Table 1 - Ultrasound transmission settings tested

Setting	Test 1	Test 2	Test 3
Transmission voltage	70	80	90
Spatial Pulse Length	2	4	6
Time-Gain Compensation	[0, 136, 271, 407, 543, 679, 814, 950]	[100, 221, 343, 464, 586, 707, 829, 950]	[200, 307, 414, 521, 629, 739, 843, 950]

Table 2 - peak distances for some of the settings in mm.

	TGC-1	TGC-2	TGC-3	SPL-6	SPL-4	SPL-2
US Distance	9.7	11.9	13.7	10.1	9.6	9.5
Difference	0.11	2.09	3.89	0.29	0.21	0.31