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The relationship between the piriformis muscle, low back pain, lower limb injuries and motor control training among elite football players

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Abstract

Objectives: Australian Football League (AFL) players have a high incidence of back injuries. Motor control training to increase lumbopelvic neuromuscular control has been effective in reducing low back pain (LBP) and lower limb injuries in elite athletes. Control of pelvic and femoral alignment during functional activity involves the piriformis muscle. This study investigated a) the effect of motor control training on piriformis muscle size in AFL players, with and without LBP, during the playing season, and b) whether there is a relationship between lower limb injury and piriformis muscle size.

Design: Stepped-Wedge Intervention

Methods: 46 AFL players participated in a motor control training program consisting of two 30 minute sessions per week over 7-8 weeks, delivered across the season as a randomised 3 group single-blinded stepped-wedge design. Assessment of piriformis muscle cross-sectional area (CSA) involved magnetic resonance imaging (MRI) at 3 time points during the season. Assessment of LBP consisted of player interview and physical examination. Injury data were obtained from club records.

Results: An interaction effect for Time, Intervention Group and LBP group ($F=3.7$, $p=0.03$) was found. Piriformis muscle CSA showed significant increases between Times 1 and 2 ($F=4.24$, $p=0.046$), and Times 2 and 3 ($F=8.59$, $p=0.006$). Players with a smaller increase in piriformis muscle CSA across the season had higher odds of sustaining an injury (OR=1.08).

Conclusion: Piriformis muscle size increases across the season in elite AFL players and is affected by the presence of LBP and lower limb injury. Motor control training positively affects piriformis muscle size in players with LBP.

Key Words: Piriformis, Australian Football League, lower limb injury, motor control training, magnetic resonance imaging.

Introduction

Low back pain (LBP) is a common problem in sports which require repetitive rotating motion and flexion or extension of the hip and spine [1]. Australian Football League (AFL) involves high intensity, continuous activities such as fast running, direction changes[2], kicking and jumping. The AFL injury report has reported high incidence and prevalence of trunk and back injuries over the last 10 years [3]. AFL also has the highest rate of non-contact soft tissue injuries compared with other football codes such as rugby league and rugby union [4], with hamstring injuries being the most prevalent injury at the elite level [5]. While many factors may contribute to injuries in elite AFL players, a growing body of literature identifies the important role of optimal neuromuscular control of the lumbopelvic region in preventing lower limb injury[6-8] and LBP[9, 10].

Control and stability of the lumbopelvic region is important in the transfer of forces between the lower limbs and spine [11]. Inability to stabilise the lumbopelvic region during dynamic lower extremity movements could lead to excessive load on joints[1]. Inadequate control of pelvic-femoral alignment (alignment of the femur relative to the pelvis) in the frontal and transverse planes may contribute to lower limb injury. Imbalances in hip and pelvic muscles involved in controlling pelvic-femoral alignment may contribute to potentially injurious misalignment of the lower extremity in the frontal and transverse planes[12]. The position of hip adduction and hip internal rotation with knee valgus and foot pronation is thought to lead to lower extremity injuries[13, 14]. Although hip adductor muscle weakness has been associated with lower limb injury in football players[15, 16], and hip abductor muscle dysfunction found in certain types of lower limb injury[17-19], little research has investigated the deeper hip muscles that control pelvic-femoral alignment in the frontal and transverse planes.

Trunk and hip neuromuscular control measurements have been shown to predict the incidence of knee injury[20]. Neuromuscular control training has been shown to improve lower extremity biomechanics and hip strength[20-22]. Recently, lumbopelvic motor control training in elite athletes was shown to increase targeted muscle size, reduce LBP [7, 9, 23], and reduce occurrence and severity of lower limb injuries[6, 7]. A relationship between motor control training and lower limb injury reduction suggests enhancement of control through the kinetic chain. Therefore motor control training targeting muscles of the lumbopelvic region may also affect other muscles involved in the control of pelvic-femoral position and stability.

Pelvic muscles provide proximal stability for movement of the lower extremity by adapting to postural and loading changes [13]. Of the deep hip muscles that control pelvic-femoral position and stability, recent EMG studies indicate that the piriformis muscle has a role in controlling transverse plane movement as a hip external rotator[24, 25]. The piriformis muscle was also found to be active during hip abduction[24, 25] and there is greatest activation of this muscle when the hip joint is in extension or requires extension[25]. During weight bearing activities, the piriformis muscle restrains excessive axial internal rotation during gait to provide optimal hip joint loading and positioning [26]. Considering its role in controlling hip abduction and rotation, studying the piriformis muscle in elite AFL players is important as it may affect the lower limb kinetic chain. However, currently, there is no research regarding the role of the piriformis muscle in lumbopelvic stability and its relationship with LBP or lower limb injuries.

This study aimed to use magnetic resonance imaging (MRI) to, a) determine the effect of a motor control training program on piriformis muscle size in AFL players, with and without low back pain, during the football playing season, and b) examine whether there is a relationship between lower limb injury and piriformis muscle size in elite football players.

Methods

Forty-six male AFL players representing the full training squad of a professional club aged 19-32 years of age were eligible to participate in the study. The mean (±SD) age, height and weight of the participants were 22.8 (±3.5) years, 187.9 (±6.0) centimetres and 88.3 (±6.6) kilograms respectively. All participants gave written informed consent and the study was approved by the relevant institution's ethics committee. No participant needed to be excluded from the study because of metal implants, claustrophobia or any other contraindication to MRI.

The intervention is a published motor control training program[6, 7]. Initially players learnt to contract abdominal and back muscles voluntarily, using feedback from ultrasound imaging. If muscles were overactive (such as inability to relax the abdominal wall), players were taught how to decrease this activity and to breathe using the diaphragm. When able, players progressed to functional weight bearing positions. Weight bearing exercises included trunk forward lean, sit-to-stand and squatting to develop spinal extensor muscle endurance. Maintenance of spinal curve and alignment of the lower limbs in functional positions were emphasised. Major goals were dissociation of hip movements from trunk movements, and increasing endurance in these functional positions. Resistance was added using Theraband (The Hygenic Corporation, Akron, OH).

The AFL playing season occurs from March to August. A single-blinded 3 group stepped-wedge design was used in which Group 3 acted as a wait-list control group for Groups 1 and 2. The intervention trial was delivered in three blocks, each of 7 or 8 weeks duration. Complete randomization was used to allocate players into one of three intervention groups. Groups 1(n=17) and 2 (n=15) received 8 weeks of motor control training. Group 1 received an additional 7 weeks of training, to assess the benefits of a prolonged intervention. Group 3 (n=14) received the training during the last 7 weeks of competition games. The motor control training consisted of two 30 minute sessions per week under the supervision of qualified physiotherapists with expertise in the motor control training program. No players were lost to follow-up.

MRI scans at the start of block 1 (Time 1), end of block 2 (Time 2), and end of block 3 (Time 3) were taken using a 1.5 Tesla Siemens Sonata MR system (Siemens AG, Munich, Germany) using a previously published protocol [7]. Participants lay supine on the imaging table in the MRI tunnel with a foam wedge under their knees. Transverse slices perpendicular to the anterior abdominal wall were taken from the lumbar spine to the hip joint, with a thickness of 8mm and an interslice distance of 0.5mm. Images were saved for later off-site analysis.

Piriformis muscle measurement used ImageJ software (Version 1.42q, National Institutes of Health, http://rsb.info.nih.gov/ij/) (See Figure 1). Muscle cross-sectional area (CSA) was measured by manually outlining the piriformis muscle boundary on 3 consecutive axial slices, from the point where the muscle was first visible on the image. The average CSA of the 3 slices was taken for each side [27]. Intra-rater reliability of piriformis muscle measurement was high (left Intra-class Correlation Coefficient ($ICC_{1,1}$)= 0.90, right $ICC_{1,1}$ = 0.99).

LBP was defined as pain localized between T12 and the gluteal fold, severe enough to interfere with sporting or training performance. An experienced physiotherapist assessed LBP by physical examination during an interview, and grouped subjects as having current LBP, history of LBP (not current) or no LBP. 'Players with current LBP' had positive findings on physical examination of the lumbar spine and reported pain in the previous week. Players with no current pain, who reported past episodes of LBP severe enough to interfere with playing games and training, were counted in the history group. 'Players with no LBP' had never experienced LBP and did not report pain on examination. Of the 46 players, 13 reported current LBP, 14 only had LBP history, and 19 had no LBP.

AFL club staff collected injury data throughout the pre-season and playing season (late November to late August). Team medical staff diagnosed each recorded injury from playing or training and determined a player's ability to participate in training. An injury was defined as a condition resulting from training or playing football that prevented a player from completing a full training session or game. Injury severity was based on players' availability for weekly competition games. This was extracted from club records of squad members available for selection in the 22 competition season games or unavailable because of injury.

Analysis of the complete dataset (n = 46) was conducted with SPSS (version 17.0; SPSS Inc., Chicago, IL, USA), and statistical significance set at $p<0.05$. Repeated measures analysis of covariance (ANCOVA) with a Type I sum-of-squares model was used to assess differences in piriformis muscle size over time and between LBP groups, with or without intervention. The repeated measures factor was 'time' (Time 1, 2 and 3). The between subjects factors were 'LBP' (coded as current or no current LBP) and 'intervention' (coded as intervention or control at T2). Age and height were included as covariates. Binomial logistic regression analysis was used to assess the effect of piriformis muscle size and the occurrence of injury during the competition playing season. Injury severity was the binomial outcome measure, coded as less than 2 games missed (n=22) versus 2 or more consecutive games missed (n=24) due to an injury, based on a sensitivity analysis to define more severe injuries[6]. The predictor variables were age, height, number of injuries in the pre-season, intervention group (coded as intervention or control at T2), LBP (coded as current or no current LBP), piriformis muscle CSA at Time 1 and percentage change in average piriformis muscle CSA between Times 1 and 3. The variable 'weight' was not included due to high co-linearity with height (r=0.75).

Results

Initial ANOVA for age and height revealed no statistically significant association between the number of players with or without LBP, or LBP history, and their distribution across the three intervention groups

(χ^2=3.6, P = 0.46). Preliminary analysis of the injured players indicated no relationship between injury side and muscle size (p>0.05), therefore injury side was not included as a factor in the final model.

Results of the ANCOVA showed an overall main effect for piriformis muscle CSA change over time ($p<0.05$). A-priori contrast for this result indicated significant differences between Times 1 and 2 (F = 0.24, P = 0.046), and between Times 2 and 3 (F = 8.59, P = 0.006) (means shown in Table 1). However, there was also a 3-way interaction effect for Time, Intervention Group and LBP group (F = 3.7, p = 0.03). Between Times 1 and 2, for players with no current LBP, the piriformis muscle CSA increased whether or not they did motor control training by Time 2. For players with current LBP, piriformis muscle CSA increased with motor control training. Between Times 2 and 3, the means show both groups' piriformis muscle CSA increased. Notably, players who had not received the intervention by Time 2 (Wait-list Control) with current LBP had a decrease in piriformis muscle size between Times 1 and 2, followed by a 20% increase in piriformis muscle CSA between Times 2 and 3, after receiving the intervention.

During the competition season, 12 players (26.1%) were available for all games and 34 (73.9%) players were injured, resulting in missing a game. Of these, 70.6% missed 2 or more games. The majority of players (67.4%) also had a pre-season injury. 21 players (45.7%) were injured in the pre-season and also the playing season. A small number (n = 4) with upper body injuries only missed one game so were not in the severity group. One player with an upper body injury also had a lower limb injury for which he missed 2 or more consecutive games (n = 1).

Table 2 shows the results of the logistic regression analysis of baseline measures related to lower limb injury during the playing season. There was a statistically significant effect for the factor of height (χ^2 = 4.47, p = 0.03) and the percentage change in piriformis muscle CSA between Times 1 and 3 (χ^2 = 4.27, p = 0.04). The odds of sustaining a severe injury (resulting in 2 or more games missed) are 16% higher for taller players (OR=1.16). In relation to change in piriformis CSA between Times 1 and 3, for every 1%

decrease below the mean percentage change (11.56 ± 13.0), there was an 8% higher odds (OR = 1.08) of incurring a severe injury during the season.

Discussion

This study found elite AFL players' piriformis muscle size increased during the playing season. Players with no LBP had an overall increase in piriformis muscle CSA at all 3 time points, whether or not they received the motor control training program. These findings indicate piriformis hypertrophy is perhaps a response to playing football and training, which included strength, endurance and game specific training. Currently, there is little understanding of the piriformis' role in lumbopelvic stability in kicking sports or single-leg stance activities. Piriformis is a deep muscle that inserts directly onto the greater trochanter from the sacrum. It exerts its effect more locally at the hip joint and allows movement of the femur to act upon the sacrum and sacroiliac joint [26]. Piriformis hypertrophy in footballers may be explained by its proposed role maintaining optimal hip joint load and positioning in stance phase, by restricting excessive axial internal rotation [26]. Because of the increased forces and muscular demands of elite level competition, it is possible that muscles vital to the athletes' performance of sports specific skills adapt accordingly.

Results also showed that LBP affected the piriformis muscle during the playing season. Players with current LBP showed reduced piriformis muscle CSA between time points 1 and 2. Assuming piriformis muscle hypertrophy across the season reflects the appropriate response to playing football, this result suggests that the presence of LBP during the season may affect the ability of the piriformis muscle to adapt in response to physical demands. Due to the difficulty in examining the piriformis muscle within the pelvis, it is often neglected in terms of musculoskeletal function and its role in lumbopelvic and hip stability. From a clinical perspective, the piriformis muscle is often subjected to soft tissue release and stretching techniques to inhibit spasm and lengthen the muscle[28]. However, there is a lack of evidence that demonstrates an understanding of the relationship between the piriformis muscle and LBP.

Motor control training was shown to affect piriformis muscle size in players with LBP. Players with LBP who underwent motor control training showed a steady increase in piriformis muscle size across the season similar to that seen in the players without LBP. The effect of motor control training was further demonstrated by players in the control group that had LBP who originally had a decrease in piriformis muscle CSA. They displayed an increase of piriformis muscle CSA by time point 3 after commencement of motor control training. That is, motor control training affected the piriformis muscle in players with LBP, maintaining or restoring piriformis muscle size similarly to players without LBP. A study by Myer et al [21] demonstrated an increase in hip strength with motor training of the trunk and hip. Our current study has found that a motor training program primarily targeting proximal muscles of the lumbopelvic region also affects the piriformis muscle that is distal to the muscles targeted in the intervention. A possible explanation for this finding is that positions adopted during motor control training of the lumbopelvic region also required activation of the piriformis muscle to maintain optimal alignment of the pelvis on the femur.

In addition, players with a relatively smaller increase in piriformis muscle CSA (Time 1 to Time 3) had higher odds of sustaining a severe lower limb injury during the playing season. Most studies in this area have assessed superficial gluteal muscles and measured hip strength in relation to lower limb injuries[18, 19, 29]. Leetun et al [29] found that weak hip external rotator muscles correlated with incidences of knee injury. It has been proposed that the inability of lumbopelvic musculature to generate appropriate force to withstand external moments at the hip and knee may affect the dynamic stability of the knee[12]. As baseline piriformis muscle size at Time 1 did not significantly predict injury, the most likely explanation for a significant relationship between piriformis muscle size and injury, is that the injury affected the piriformis muscle. However, reduced training load during recovery from a severe lower limb injury may also explain the smaller increase in piriformis muscle size. Nadler et al [30] have shown that lower limb overuse or acquired ligamentous injuries increased the risk of LBP in athletes. The findings of the current study suggest that piriformis muscle hypertrophy across the season in response to physical demands was affected by the presence of a lower limb injury. This link may be due to the entire lower extremity being one continuous kinetic chain, where an injury may lead to muscle changes in proximal or distal body areas.

Additional findings from this study indicated that height was a risk factor for injury. As indicated in Hides et al [6] shorter players had less chance of sustaining a severe injury during the season. Pre-season injury was not found to be a predictor of injury during the season. The main limitation to this study is the small sample size which is characteristic of studies in this area, and results from elite athletes. The number of players with LBP in this study was relatively small and further studies on a larger sample should be conducted to validate this finding. Further research examining the piriformis muscle and other deep hip musculature could help researchers understand the clinical significance of muscles of the hip and pelvic region, and their effect on LBP and the lower limb. Use of ultrasound imaging rather than MRI would be more cost effective, and use of clinical tests such as dynamometry could provide additional information in future research.

Conclusion

This study found changes of deep hip musculature in elite footballers which were related to LBP and lower limb injury. Motor control training of the lumbopelvic region had beneficial effects on the size of the piriformis muscle.

Practical Implications

- Rehabilitation of lower limb injuries should involve motor control training of the lumbopelvic region.
- Motor control training effectively maintains or restores piriformis muscle size

- This study supports ongoing research into deep hip and pelvic musculature in LBP and injury

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References

1. Harris-Hayes M, Sahrmann SA, Van Dillen LR: Relationship Between the Hip and Low Back Pain in Athletes Who Participate in Rotation-Related Sports. *Journal of Sport Rehabilitation* 2009, 18(1):60-75.
2. Dawson B, Hopkinson R, Appleby B *et al*: Player movement patterns and game activities in the Australian Football League. *J Sci Med Sport* 2004, 7(3):278-291.
3. Orchard J, Seward H, Orchard J: 20th Annual Injury Report: Season 2011. In. Sydney, Australia: AFL Medical Officers Association; 2012.
4. Seward H, Orchard J, Hazard H *et al*: Football Injuries In Australia At The Elite Level. *Med J Aust* 1993, 159(5):298-301.
5. Orchard J, Seward H: Epidemiology of injuries in the Australian Football League, seasons 1997-2000. *Br J Sports Med* 2002, 36(1):39-44.
6. Hides J, Stanton W: Can motor control training lower the risk of injury for professional football players? *Med Sci Sports Exerc* 2014, 46(4):9.
7. Hides JA, Stanton WR, Mendis MD *et al*: Effect of Motor Control Training on Muscle Size and Football Games Missed from Injury. *Med Sci Sports Exerc* 2012, 44(6):1141-1149.
8. Hides JA, Brown CT, Penfold L *et al*: Screening the Lumbopelvic Muscles for a Relationship to Injury of the Quadriceps, Hamstrings, and Adductor Muscles Among Elite Australian Football League Players. *J Orthop Sports Phys Ther* 2011, 41(10):767-775.
9. Hides J, Stanton W, McMahon S *et al*: Effect of stabilization training on multifidus muscle cross-sectional area among young elite cricketers with low back pain. *J Orthop Sports Phys Ther* 2008, 38(3):101-108.
10. Hides JA, Boughen CL, Stanton WR *et al*: A Magnetic Resonance Imaging Investigation of the Transversus Abdominis Muscle During Drawing-in of the Abdominal Wall in Elite Australian

Football League Players With and Without Low Back Pain. *J Orthop Sports Phys Ther* 2010, 40(1):4-10.

11. Kibler WB, Press J, Sciascia A: The role of core stability in athletic function. *Sports medicine (Auckland, NZ)* 2006, 36(3):189-198.

12. Colston MA: Core Stability, Part 2: The Core-Extremity Link. *International Journal of Athletic Therapy & Training* 2012, 17(2):10-15.

13. Willson JD, Dougherty CP, Ireland ML *et al*: Core stability and its relationship to lower extremity function and injury. *J Am Acad Orthop Surg* 2005, 13(5):316-325.

14. Willson JD, Ireland ML, Davis I: Core strength and lower extremity alignment during single leg squats. *Med Sci Sports Exerc* 2006, 38(5):945-952.

15. Thorborg K, Branci S, Nielsen MP *et al*: Eccentric and Isometric Hip Adduction Strength in Male Soccer Players With and Without Adductor-Related Groin Pain: An Assessor-Blinded Comparison. *Orthopaedic Journal of Sports Medicine* 2014, 2(2).

16. Crow JF, Pearce AJ, Veale JP *et al*: Hip adductor muscle strength is reduced preceding and during the onset of groin pain in elite junior Australian football players. *J Sci Med Sport* 2010, 13(2):202-204.

17. Franettovich Smith MM, Honeywill C, Wyndow N *et al*: Neuromotor Control of Gluteal Muscles in Runners with Achilles Tendinopathy. *Med Sci Sports Exerc* 2014, 46(3):594-599.

18. Morrissey D, Graham J, Screen H *et al*: Coronal plane hip muscle activation in football code athletes with chronic adductor groin strain injury during standing hip flexion. *Man Ther* 2012, 17(2):145-149.

19. Cowan SM, Crossley KM, Bennell KL: Altered hip and trunk muscle function in individuals with patellofemoral pain. *Br J Sports Med* 2009, 43(8):584-588.

20. Zazulak BT, Hewett TE, Reeves NP *et al*: Deficits in neuromuscular control of the trunk predict knee injury risk - A prospective biomechanical-epidemiologic study. *Am J Sports Med* 2007, 35(7):1123-1130.

21. Myer GD, Brent JL, Ford KR *et al*: A pilot study to determine the effect of trunk and hip focused neuromuscular training on hip and knee isokinetic strength. *Br J Sports Med* 2008, 42(7):614-619.

22. Myer GD, Chu DA, Brent JL *et al*: Trunk and hip control neuromuscular training for the prevention of knee joint injury. *Clin Sports Med* 2008, 27(3):425-448.

23. Hides JA, Stanton WR, Wilson SJ *et al*: Retraining motor control of abdominal muscles among elite cricketers with low back pain. *Scand J Med Sci Sports* 2010, 20(6):834-842.

24. Hodges PW, McLean L, Hodder J: Insight into the function of the obturator internus muscle in humans: Observations with development and validation of an electromyography recording technique. *J Electromyogr Kinesiol* 2014(In Press).

25. Giphart JE, Stull JD, LaPrade RF *et al*: Recruitment and Activity of the Pectineus and Piriformis Muscles During Hip Rehabilitation Exercises An Electromyography Study. *Am J Sports Med* 2012, 40(7):1654-1663.

26. Snijders CJ, Hermans PFG, Kleinrensink GJ: Functional aspects of cross-legged sitting with special attention to piriformis muscles and sacroiliac joints. *Clin Biomech* 2006, 21(2):116-121.

27. Grimaldi A: MRI Investigations of the muscles involved in lateral stability of the hip [PhD Thesis]. St Lucia, QLD: University of Queensland; 2008.

28. Miller TA, White KP, Ross DC: The Diagnosis and Management of Piriformis Syndrome: Myths and Facts. *Can J Neurol Sci* 2012, 39(5):577-583.

29. Leetun DT, Ireland ML, Willson JD *et al*: Core stability measures as risk factors for lower extremity injury in athletes. *Med Sci Sports Exerc* 2004, 36(6):926-934.

30. Nadler SF, Wu KD, Galski T *et al*: Low back pain in college athletes - A prospective study correlating lower extremity overuse or acquired ligamentous laxity with low back pain. *Spine* 1998, 23(7):828-833.

Table 1: Marginal means and standard error (adjusted for age, height and weight) of the piriformis muscle CSA for players with current LBP and players with no current LBP based on whether intervention was received by the end of Time 2.

LBP	Intervention by Time 2	TIME 1 (Mean ± SE)	TIME 2 (Mean ± SE)	TIME 3 (Mean ± SE)
No current LBP n = 33	Yes	13.83 ± 0.47	14.51 ± 0.56	15.55 ± 0.60
	No	13.93 ± 0.70	14.97 ± 0.83	15.35 ± 0.88
Current LBP n = 13	Yes	14.51 ± 0.77	15.74 ± 0.92	16.15 ± 0.97
	No	13.42 ± 1.12	**12.06 ± 1.34**	14.51 ± 1.41

CSA measurements in cm^2

Table 2: Logistic regression results for variables related to sustaining an injury resulting in 2 or more games missed.

Variables[a]	Chi-Square	Odds Ratio	95% Confidence Interval
Intervention **(Yes)**	3.36	0.21	(0.04, 1.12)
Height **(Taller)**	**4.47***	**1.16**	**(1.01, 1.34)**
Age **(Older)**	0.00	1.01	(0.80, 1.25)
Preseason Injuries **(Higher)**	2.98	2.41	(0.89, 6.52)
Current LBP **(Yes)**	1.19	0.95	(0.88, 1.04)
Piriformis CSA at Time 1 **(Bigger)**	0.02	0.97	(0.69, 1.37)
% increase in piriformis CSA Time 1 and 3 **(Smaller)**	**4.27***	**1.08**	**(1.01, 1.16)**

*: $p<0.05$, a: For each variable, odds ratio refers to category in bold

Figure 1: Axial MRI through the pelvis with the piriformis muscle on both sides outlined using ImageJ software.

Figure 1